THE SCATTERING OF X-RAYS

AND

THE J-ABSORPTION PHENOMENON.

by

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(THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.)

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Introduction.

A difference between the absorbabilities of the primary and the secondary X-radiations, scattered from light elements (even in the absence of any known characteristic radiation), was observed in the earliest experiments on the subject by Barkla[1], Sagnac[2], Beatty[3], Sadler & Mesham[4] and J. Laub[5]. This was confirmed by J.A. Gray[6] and later on by A.H.Compton[7] and J.A. Crowther[8]. A similar difference in absorption of the primary and secondary beams of γ-rays, has also been known for a long time. Eve[9], R.D. Kleeman[10], Madsen[11], Ishino[12], D.C.H. Florence[13] J.A. Gray and A.H. Compton's experiments leave no doubt as to the difference in the absorption coefficients of the primary and secondary radiations.

Two possible explanations of greater absorption of the secondary beam have been pointed out. The first is the variation of scattering with the wave-length which is so marked in elements of high atomic number. Longer waves are scattered most;

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1. Barkla, Phil.Mag.June 1904 May 1903
2. Sagnac, Comptes Rendus.
3. Beatty, Phil. Mag.
4. Sadler & Mesham, Phil.Mag. May 24, 1912
5. Laub, Ann.Phy. XL VI 1915
6. Gray, Phil.Mag. 26 1913 Tans.Roy.Soc.Canada Sec. 3, 1922 Frank.Inst.J.190 Nov. 1920
7. A.H.Compton, Phil.Mag. 41 1921 Nature CVIII 1921 Phil.Mag.1921 May Phys.Review 22 1923 Phys.Review Aug.1923
8. Crowther, Phil.Mag. XLII 1921
9. Eve, Phil.Mag. 8, 1904
10. Kleeman, Phil.Mag. 15, 1908
11. Madsen, Phil.Mag. 17, 1909
12. Ishino, Phil.Mag. 37, 1919
13. Florence, Phil.Mag.27, 1914 Phil.Mag.22, 1916

and so in the scattered beam, the radiations of longer wave-lengths preponderate. The second is the emission of an X-radiation, (a tertiary radiation)* from the radiator due to the bombardment of the radiator by electrons, ejected from other atoms of the same substance by the primary rays. These phenomena, it was originally considered, might in many cases at least, explain the differences that were observed between the absorbabilities of the primary and secondary beams. In scattering from light substances (e.g. filter paper, paraffin wax, carbon,) however, these phenomena cannot affect the absorbability of the secondary beam to any appreciable extent.

The real difference in absorbabilities of the primary and secondary beams from light elements, might be accounted for, in one of two ways; either, on the hypothesis of some new series of characteristic radiations, emitted by the radiator, or on the hypothesis of a change of wave-length in the process of scattering.

The first hypothesis, which was once strongly supported by A.H. Compton,[1] had its support from various considerations. A new series of characteristic radiation had been reported to exist in the Bakerian lecture for 1916 by Barkla.[2] All his experiments on (a) ionisation, (b) corpuscular radiations

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*. Clark & Duane, Proc.Nat.Ac.Sc.Dec.1923 Jan.Feb.March 1924.
1. A.H.Compton, Phys.Rev.18, Aug.1921, Phil.Mag.41,1921
2. Barkla, Phil. Trans.Roy.Soc.London, Series A.Vol.217, 1916.

* Clark & Duane, in recent spectroscopic work with heavier elements claim to have detected the lines due to the tertiary radiations from heavy scattering substances.

(c) absorption and (d) X-ray fluorescence (excitation by primary X-radiation) suggested very strongly the existence of a series of hard fluorescent radiations, - called by Barkla the J-series, because the radiation of this new series (supposing that it existed) appeared to be harder (i.e. of shorter wave-length) than the K-radiation emitted by the same elements. In a later paper by Barkla and White[1], definite discontinuities were shown to exist in their curves, where absorption-coefficients of X-rays beams in different substances e.g. aluminium, water, filter paper, paraffin wax - were plotted against absorption-coefficients in copper. They associated these absorption discontinuities with the emission of high frequency characteristic radiations from the different substances, namely, carbon, oxygen, aluminium, and copper itself - and from sulphur also (as shown by ionisation experiments). Such discontinuities were also recorded by Dauvillier[2], Owen[3], and Williams[4].

Crowther[5] also, on the assumption that the apparent softening of the secondary radiation was due to the superposition of a fluorescent radiation on the scattered beam - concluded that radiations of wave-lengths given in column II of the following table - were emitted.

Radiator	Wave-length x 10^{-8} cm. I primary	II secondary
Paraffin	.38	.43
Aluminium	.41	.51
Copper	.36	.46

1. Barkla & White, Phil. Mag. Oct. 1917
2. Dauvillier Ann. de ph. XVI 1920
3. Owen, Proc. Roy. Soc. London 1919
4. Williams, Proc. Roy. Soc. London 1919
5. Crowther, Phil. Mag. 42, 1921

Compton's early experiments too, as has already been remarked indicated the existence of a type of high-frequency fluorescent radiation whose wave-length was independent of the particular substance, used as radiator, and dependent only on the frequency of the exciting primary rays.

The possibility of a fluorescent (characteristic) radiation was also suggested by the result of other experiments. There were large discrepancies between the values obtained by various observers for the co-efficient of scattering from different elements. These discrepancies were considerably greater than any possible error of experiment and therefore suggested that the radiation measured was not pure scattered radiation, but that the scattered radiation was accompanied by a very considerable amount of X-radiation of different origin. Crowther[1] obtained a value of the scattering co-efficient $\frac{\sigma}{\rho}$ for Al as high as 1.18, and his later experiments[2] by a different method gave the values of $\frac{\sigma}{\rho}$ for a radiator of filter paper as .27, and for aluminium .28. Barkla's[3] value of $\frac{\sigma}{\rho}$ for carbon on the other hand, was exactly .20 as is expected from J.J. Thomson's formula. Lower values also have been obtained by other investigators.[4]

The distribution[5] of the scattered radiation around the radiator showed variations too. It varied considerably with the quality of the primary radiation employed to excite it, and in some cases it varied with the thickness of the radiator.[6] The existence of a

1. Crowther, Proc. Roy. Soc. Lond. A LXXXVI 1911
2. Crowther, Proc. Roy. Soc. A LXXXVI 1912
3. Barkla, Phil. Mag. 1911
4. Hewlett, Phys. Rev. 17 Mar. 1921, Olson, Elmer, Dershem & H.H. Storch Phys. Rev. Jan, 1923.
5. Crowther, Proc. Roy. Soc. LXXXVI, 1912
6. Crowther, Proc. Camb. Phil. Soc. XVI 1911

fluorescent radiation might qualitatively explain these anomalies.

Furthermore, Crowther,[1] pointed out another argument in favour of the existence of a high frequency radiation from analogy with γ- radiation. It had been shown by Rutherford and Robinson[2] that the β- rays excited by the γ-radiation from Radium C consist of a series of groups with a characteristic and a very definite velocity. It is assumed that each group of β- rays is produced by γ-rays of definite wave-length. The β-ray spectrum thus consists of a considerable number of characteristic lines.[3] (Ellis[4] has recently confirmed these conclusions). Knowing the frequencies of these lines the frequency of a corresponding high-frequency characteristic radiation in X-rays can be calculated. The calculated wave-lengths range from 2.7×10^{-8} cm. to $.24 \times 10^{-8}$ cm. Barkla and White's discontinuities are within this range.

As regards the second hypothesis - that of a possible change of wave-length in the process of scattering - there originally, when X-rays were considered as radiations consisting of discontinuous pulses - appeared the possibility of a change in the properties of radiation, produced by the process of scattering by electrons or groups of electrons subject to restraining forces within the atom. This change, however, was regarded as negligible in the case of scattering from loosely held electrons in light elements. With long wave-trains however, the frequency of the excited scattered radiations should <u>in all cases</u> be equal to the frequency of the primary X-radiations. So, on the classical theory, there should be no change of wave-length on scattering.

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1. Crowther, Phil. Mag.42, 1921 . 2. Rutherford & Robinson, Phil.Mag.28, 1914

3. ~~Lise Meitner~~ An alternative explanation of this, in view of Compton's quantum theory is suggested by Lise Meitner. Zeits. für Physik 19, 5 & 6 1923

4. Ellis, Proc. Roy. Soc. A. 1921

Very recently in a number of papers, quite a novel and interesting theory of scattering on a quantum basis has been brought forward by A.H.Compton, demanding a change of wave-length to take place, during the process of scattering. Compton's theory will be discussed later, in view of the experimental results obtained in the present investigation.

The object and scope of the present investigation.

The evidence of transformation by a change of wave-length, or by an excitation of a new characteristic radiation - a J-radiation - was looked for by Barkla & Sale, by quite a sensitive method. The result showed no sign of any transformation taking place over a considerable range of wave-length. They used primary radiations, direct from the X-ray tube and obtained the variation of the wave-length by adjustment of gas pressure in the tube, the potential applied to the tube and by filtering the radiation. Sheets of paper as the scattering substance were placed with the surface making an angle of 45° with the axis of the beam. The correction for scattering from air and all stray-effects having been made, the curve obtained for $\frac{I_s}{I_p}$ i.e.

$$\frac{\text{Ionisation by the Secondary beam}}{\text{Ionisation by the Primary beam}}$$

at various wave-lengths, was a smooth continuous line, with a slight downward slope towards the harder end. Had there been an emission of a characteristic radiation (or radiations) from paper, this would have been apparent as a sudden rise in the above ratio, due to a fluorescent radiation, appearing at a particular wave-length (corresponding, ~~as~~ it was expected, to that, at which Barkla & White observed increased absorption). These results are of great interest

1. A.H. Compton Bull. N.R.C. Oct. 1922. Phys. Rev. XXI Dec. 1923 May 1923 Phil. Mag. Nov. 1923
2. Barkla & Sale Phil. mag. XIV 1923.

for, the emission of even a feeble characteristic X-radiation from one of the constituent elements or a sudden small change in the wave-length of the scattered ray would have been clearly detected in the form of the curve. Curves for Aluminium and copper as radiators were also continuous and showed no sign of any such superposed radiation or any sudden change in the wave-length of the scattered beam. It has however, been pointed out by Barkla and Sale, that the rise to be expected from the absorption experiments is an exceedingly small one; for the change of absorption which Barkla and White observed, was about a 15%-rise, and in the case of the K-radiation, only a small fraction of the energy absorbed in light elements (i.e. of 15%) has been found to be transformed into characteristic radiation. In these experiments, the experimental error was about 3% and one could not be certain of detecting a variation of less than about that magnitude. Consequently the evidence, that the radiation did not exist, was not conclusive. This argument has not such force, in the case of elements of higher atomic weight; for the amount of energy transformed into characteristic radiation is greater, the higher the atomic weight. Hence if "J" radiation really existed, it ought to have shown itself in the form of the "Intensity" - curves for aluminium or copper as radiators. The absence of evidence of a discontinuity either in the aluminium or in the copper curve threw not a little doubt on the existence of the so-called "J" radiation. The idea of a sudden change in wave-length on scattering was not supported either.

On the other hand, there was distinct evidence of a sudden transformation in the direct experiments of Barkla and Sale on comparison of the penetrating powers of the primary and secondary radiations from light elements. They used thin sheets of paper as the scattering substance at an angle of 45° to the incident primary beam, and so practically avoided all error due to differential absorption of the primary and secondary beams. Their experiments showed that within the limits of experimental error, which was about 3%, the scattered beam had the same absorption-coefficient as the primary over a big range of wave-lengths at the soft end. (The range did not include the wave-length of the J-absorption discontinuity observed by Barkla and White.) In the region of higher frequencies, however, a decided difference was observed between the absorption-coefficients of the primary and secondary beams. From these results, one can clearly see that under some conditions (at the soft end), purely scattered radiation, without change in wave-length and without admixture of fluorescent radiation can be obtained from light substances, while (at the hard end) there is a decided change in the absorption-coefficient of the secondary radiation under the conditions of these experiments. Now, if such an abrupt transformation had actually taken place <u>in the scattering substance</u> it would have been expected to give quite a large sudden increase in the ratio of ionisations in the secondary and primary electroscopes when they received the "unintercepted" beams, because a change in absorbability is always associated with a change in ionising power, the effect of which should have been clearly evident in the secondary electroscope.

The absence of any such sudden change in the "unintercepted ratio" (Secondary / primary) over a large range of wave-lengths

- led us to consider very critically the transformation that has been observed in the absorption experiments of Barkla and Sale, and previously by Crowther and Compton. It also raised grave doubts as to the existence of J-radiations, associated with the discontinuities in absorption and ionisation observed by Barkla and White, Dauvillier, Williams, and Owen. Even if it were supposed that the discontinuities could be explained on the hypothesis of a characteristic radiation or radiations being emitted under certain unknown conditions, these transformed radiations could not possibly be subject to the same laws as those governing the fluorescent radiations of series K, L, M, or N. It looked as though the transformation observed in the absorption experiments of Barkla and Sale was independent of the process of scattering and made one suspect that it might have its origin in the process of transmission through the aluminium used for measurements of absorption-coefficients. The possibility of an explanation in this direction, was not very remote, especially in view of the absorption discontinuities observed by Barkla and White and others. The present investigation was therefore undertaken to look into these possibilities and to obtain further knowledge about the transformation observed and its relation, if any, to this mysterious absorption phenomenon.

The general conclusions from all the experimental results which are embodied in the following pages are significant. They show convincingly that whatever may be the ultimate cause of the J-discontinuities - the softening of the scattered beam is explained by the J-absorption phenomenon as has already been pointed out by Barkla[1] in a note to Nature, on the basis of many of these

1. Barkla, Nature, Nov. 17, 1923.

experimental results. In many cases, at any rate, such changes as have been observed, occur quite definitely outside the scattering substance. They are, then, independent of the process of scattering. This is decidedly against Compton's recent "quantum" theory of scattering, demanding a change of wave-length in the process of scattering.

The change observed in the wave-length of the scattered γ -radiations too, may also be conjectured, as not essentially associated with the simple process of scattering.

In addition to the discontinuity observed by Barkla & White, other discontinuities have been detected at the soft end. The main characteristics of these discontinuities have been investigated, and certain generalisations, concerning the phenomenon, have been arrived at.

Apparatus and Method.

Unless otherwise stated, an ordinary 7 inch "Reliance-tube" with tungsten anticathode was used for producing beams of X-rays. To get very soft rays, a specially pumped tube of the same type was used. To excite the tube, an ordinary induction coil with Mercury-Paraffin-Oil-interrupter was always used. The voltage applied to the coil was usually 20. The hardness of the tube was adjusted, by varying the current through the tube, by regulating the gas pressure within the tube, with the help of the "softener" and by manipulating the speed of the interrupter.

All the experiments can be classed as follows:

Experiments I.

(Measurements of the ratio of ionisations by secondary and primary radiations when unintercepted).

These experiments were exactly along the same line as Barkla

STUDIES IN

THE J-TRANSFORMATION OF SCATTERED X-RADIATION.

BY

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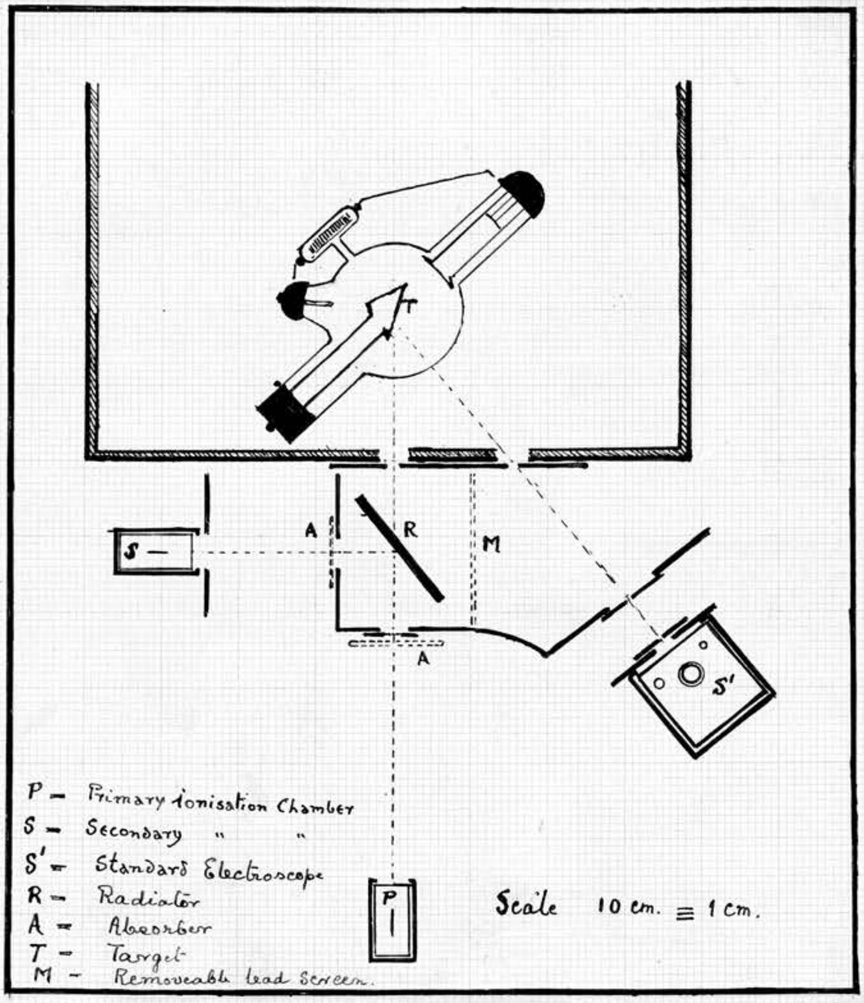

FIG 1.

& Sale's experiments. Sheets of filter papers were held in an aluminium frame, which could be adjusted exactly to an angle of 45° to the axis of the primary beam, incident on the radiator. (See fig. 1.)

The ionisation produced by the secondary radiations emerging from the second face of the sheets, in a direction at right angles to the primary radiation, was then measured. Since the sheets were inclined at an angle of 45° to the axis of the primary beam, errors due to absorption in paper, affected the primary and secondary beams in the same degree; so in comparing the ionisation produced by the secondary beam, with that produced by the primary beam, there was very little error, due to differential absorption. With thin sheets of paper, as the scattering substance, the error was quite negligible.

Two similar ionisation chambers with sulphur dioxide at a pressure slightly above atmospheric pressure, were used, to measure the intensities. The secondary beam was passed successively through two circular apertures, each of 4.5 cm. diameter, one very near to the radiator and the other, just in front of the ionisation chamber. The primary beam, after transmission through the scattering substance, passed through a number of pin - holes in a lead screen, placed very near to the radiator. The front of the ionisation chamber for the secondary beam, was at a distance of about 25 centimeters from the middle of the scattering substance; and the corresponding distance for the electroscope in the primary beam, was about 44 centimeters in most of the experiments.

TABLE I.

ttering from Paper

kla and Khastgir

primary	Observed ratio of intensities scattered / primary (in arbitrary units)
1.23	1.00 × x
1.29	1.00
1.58	1.02
1.64	1.02
1.68	1.02
1.69	1.02
1.84	1.06
1.99	1.07
2.14	1.07
2.20	1.08
2.58	1.09
2.62	1.08
2.69	1.07
2.71	1.08
3.21	1.09
3.63	1.08
4.75	1.095
4.88	1.09

Barkla and Sale

$\frac{\mu}{\rho}$ primary	Observed ratio of intensities scattered / primary (in arbitrary units)
.40	·203 × y
·44	·205
·55	·207
.87	·201
1·27	.206
1.48	·209
1.97	·212
2·07	·215
2·41	·213
2·70	·221
3·47	·216
4·20	·223

Vide Fig. 2(a) & Fig. 2(b)

The ionisation chambers were cylinders of length 9.5 centimeters and 4.5 centimeters diameter, with very light aluminium electrodes in the middle, along the axis, which were properly insulated. The outer surfaces of the chambers were earthed and the electrodes had connections with the gold-leaf-systems of electroscopes.

The electroscopes were two ordinary gold-leaf electroscopes and were charged from the town mains. In most of the experiments, travelling microscopes were used to measure the fall of the gold-leaves.

Scattering from air and other stray effects were looked for; in many cases the effects were very small ; and even when not quite negligible , they were practically constant over the whole range of wave-lengths under investigation. It is therefore unnecessary to consider these further, when studying abrupt discontinuities.

As SO_2 was used in the ionisation chambers, a thin sheet of aluminium (thinnest that could be effectively used, about ·009 cm.) had to be used in front of each of the chambers. Strictly speaking, the primary and the secondary beams were not therefore unintercepted. Besides a layer of air, the thin sheet of aluminium was always in their path.

Table 1. gives the ratio $\frac{I_s}{I_p}$ (namely, $\frac{\text{Ionisation by secondary rays}}{\text{Ionisation by primary rays}}$) over a fairly long range of wave-lengths. In the same table are shown Barkla & Sale's results for comparison. In Fig. 2 (a) is given the graphical representation of the results of the present

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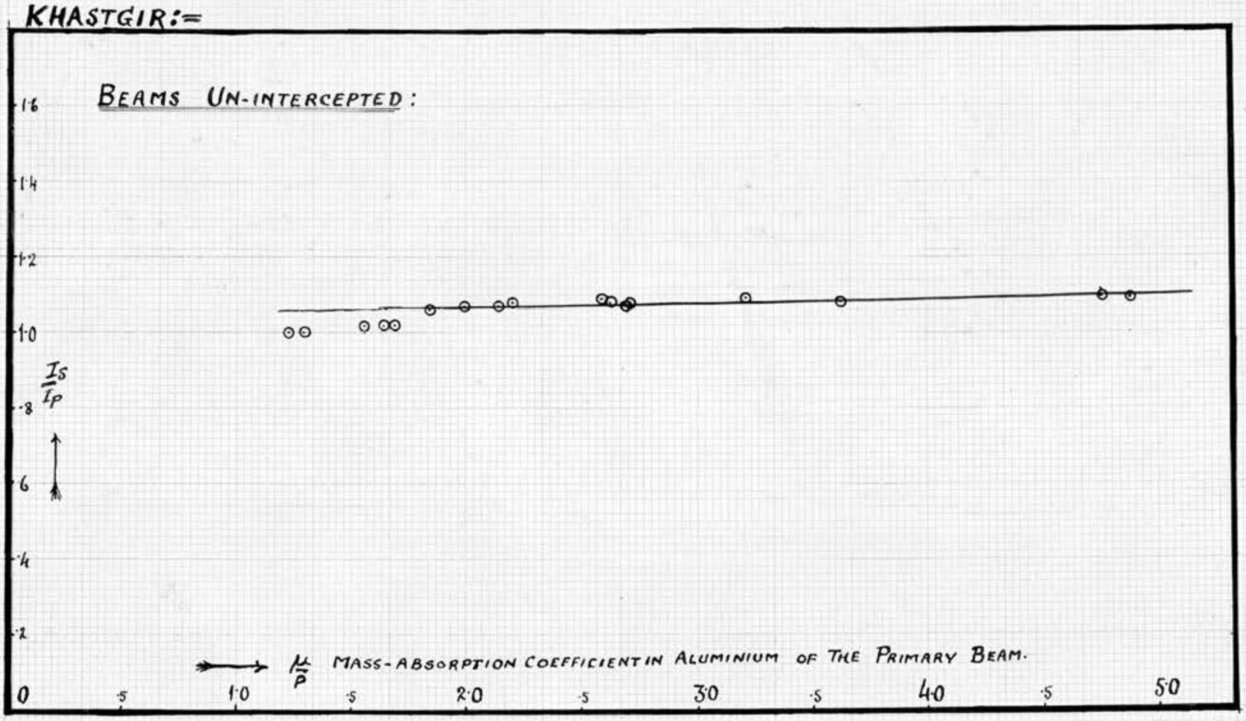

FIG 2(a)

BARKLA & SALE:

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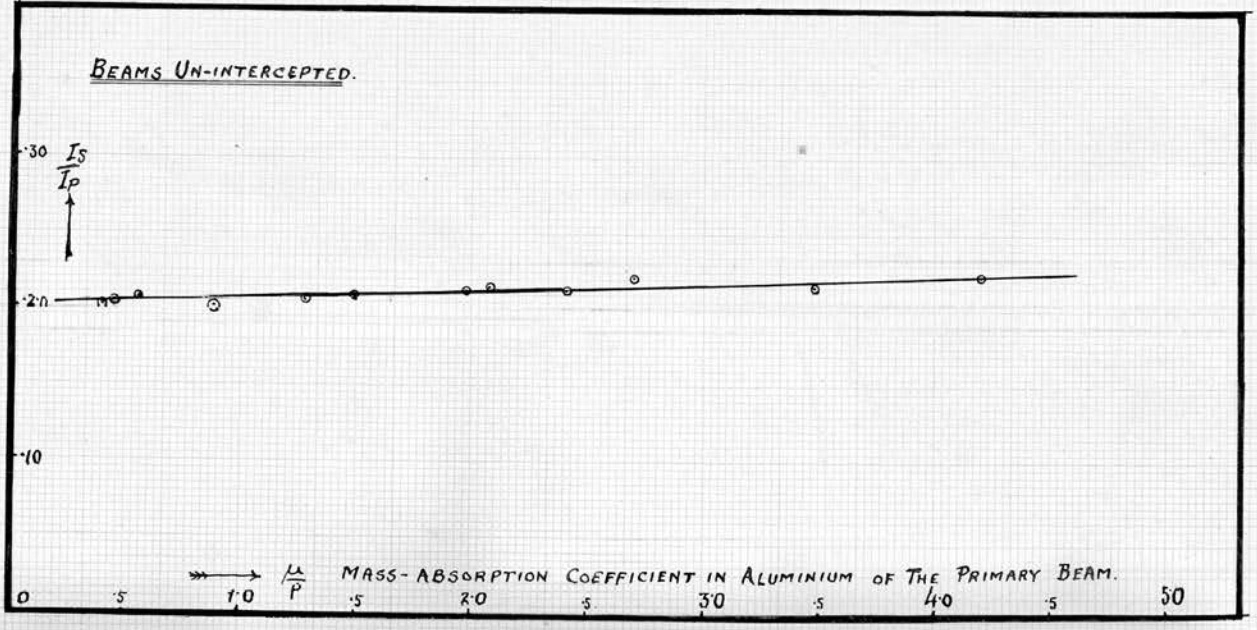

FIG. 2(b)

investigation, while, Barkla & Sale's curve for scattering from paper is given in Fig. 2 (b). The range of wave-lengths in the present investigation was not extended far, towards the region of shorter wave-lengths.

In Fig. 2 (a), where the ratio of the ionisations by the ~~scattered~~ secondary and primary radiations in arbitrary units is plotted against the absorbability in aluminium of the primary beam - it is clearly seen that over a long range, from $\left(\frac{\mu}{\rho}\right)_{Al} = 1.2$ to $\left(\frac{\mu}{\rho}\right)_{Al} = 5.0$, the variation of scattering with wave-length is very slight, and there is no sign of any discontinuity which was expected at the point where Barkla & Sale observed a sudden change in the absorption-coefficient of the secondary beam. This is a mere confirmation of Barkla & Sale's previous work.

There was however, a very slight break of about 3 to 4% in the curve shown in Fig. 2 (a), when $\frac{\mu}{\rho} = 1.7$ nearly. This was not a spurious result. It was noticed in nearly all the experiments. The reason appeared to be clear, in view of later experimental results.

Reference will be made later, to some noticeable features which were observed in some of the curves for thin sheets of paper as the scattering substance.

Experiments II

(Measurements of The Ratio $\frac{\text{Secondary}}{\text{Primary}}$ when The Beams were Intercepted)

These experiments were just the same as the previous experiments except for the fact that equal thicknesses of an absorbing substance, (e.g. aluminium, copper, or paper) were interposed in the path of both the primary and the secondary beams. The ionisation by the ~~scattered~~ secondary beam was compared, over a wide range of wave-lengths, with the ionisation by the primary beam, after each of the beams had passed through the same thickness of the absorbing material.

As a remarkable contrast with the unbroken curves for the unintercepted beams, there appeared three distinct breaks, within the range of wave-lengths under investigation. For the sake of convenience, these may be called J_1 J_2 and J_3 discontinuities, reckoned from the soft end. See Figs. 3 (a), 4 and 5 (a), each of which shows one discontinuity. (The accuracy needed, made it undesirable to attempt to study more than one discontinuity at a time). It should be pointed out, that each discontinuity was passed over, in both directions, i.e. the step was passed over, with increasing as well as with decreasing wave-lengths, as can be seen from the order of measurements taken. (See Tables II, III, IV, and V). The steps always appeared at about the same spot, not only in one, but in a number of experiments.

The position of the discontinuities was however, seen to depend to a slight extent, on the thickness of the absorber. In the case of aluminium as absorber when the thickness was just sufficient to cut off 50% or so, of the original radiation, the position of the J_1-discontinuity, corresponded approximately with the point at which Barkla & Sale observed the sudden increase to take place in the absorption coefficient of the secondary beam. This had indicated that, the sudden change in the absorption coefficient of the secondary beam, was due to a sudden increase in absorption in <u>the absorbing material</u>. This was borne out by the comparison of the curve for the "unintercepted" beams and the curve for the "intercepted" beams, measurements of $\frac{I_s}{I_P}$ in the two cases, being made alternately for one particular radiation. Up to a certain value of the absorption coefficient of the primary beam,

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J_1 - DISCONTINUITY :

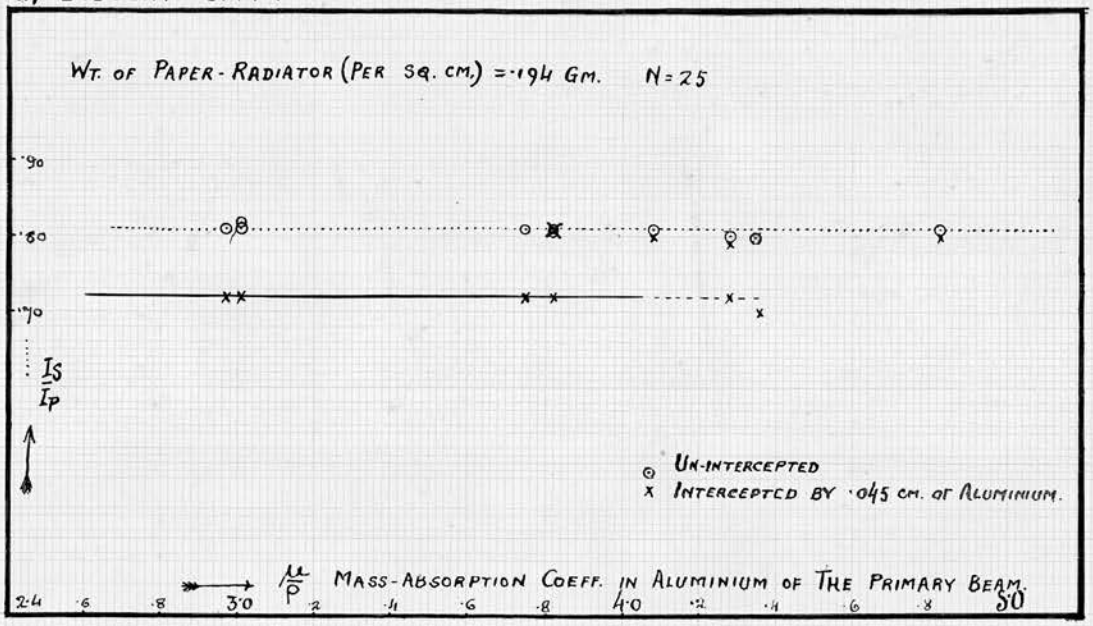

FIG. 3(a)

J_1 - DISCONTINUITY :

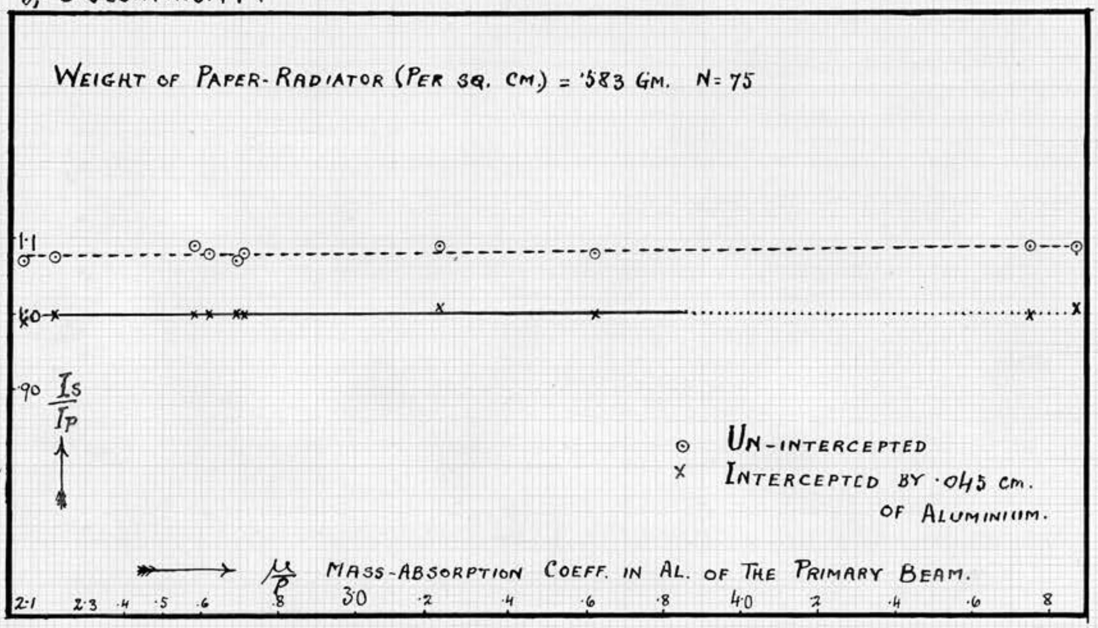

FIG. 3(b)

TABLE II.

- Discontinuity: Thickness of Aluminium Absorber = .045 cm.

Weight of paper radiator per sq.cm.= ·194 gms. of Paper Sheets as Radiator = 25			Weight of paper radiator per sq.cm.= ·583 gms. No. of paper Sheets as Radiator = 75		
Primary	$\frac{I_s}{I_p}$ Unintercep. (arbitrary units)	$\frac{I_s}{I_p}$ Intercepted. (arbitrary units)	$\frac{\mu}{\rho}$ Primary	$\frac{I_s}{I_p}$ Unintercep. (arbitrary units)	$\frac{I_s}{I_p}$ Intercepted.
3·01 (approx.)	.82 xx	.72 xx	3.62	1.08 xy	1.00 xy
4.28	.80	.79)	4.75	1.09	1.00
		.72)	4.87	1.09	1.01
4.83	.81	.80	3.22	1.09	1.01
3.82	.805	.72	2.69	1.07	1.00
4.08	.81	.80			
4.36	.80	.70 *	2.58	1.09	1.00
3.01	.81	.72	2.20	1.075	1.00
3.82	.81	.81	2.62	1.08	1.00
3.17	.81	.72	2.71	1.08	1.00
2.97	.81	.72	2.14	1.07	.99
3.75	.81	.72			
	VIDE FIG. 3(a)			VIDE FIG. 3(b)	

TABLE III.

Weight of Paper Sheets (N = 75) as Radiator = ·583 gms per sq. cm.

rimary	Observed Ratio of Intensities Unintercepted	Observed Ratio of Intensities $\frac{I_S}{I_P}$ Intercepted by ·09 cm. of Al.
3.71	..	.52 x x (arbitrary units)
3.34	..	.56?
4.67	..	.60
4.76	..	.60
3.27	..	.52
2.96	..	.50
2.69	..	.52
3.06	..	.51
2.90	..	.51
2.80	..	.53
4.19	..	.59
4.08	..	.59
3.82	..	.55?

VIDE FIG. 4.

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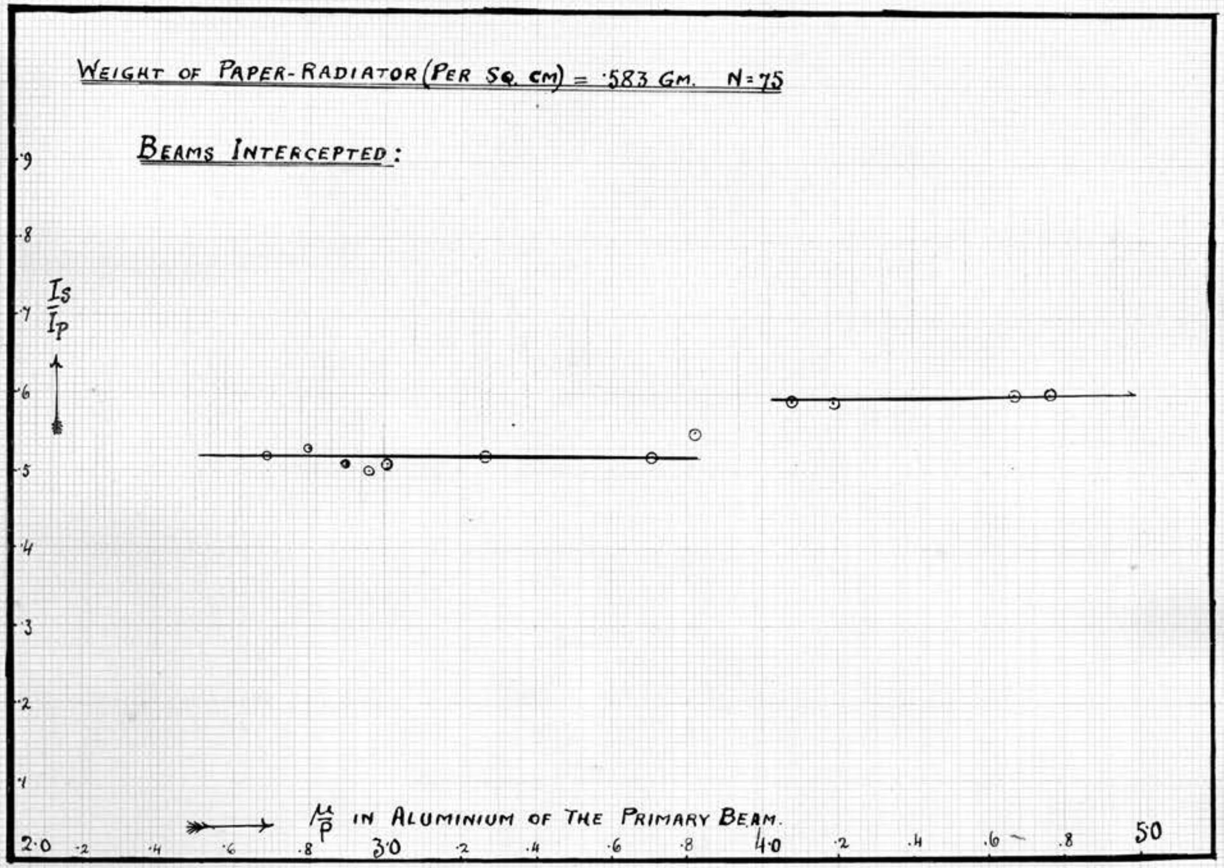

Fig 4.

the ratio $\frac{I_s}{I_p}$ in both cases, namely (1) when there was no absorber in the paths of the secondary and the primary beams and (2) when equal thicknesses of aluminium were interposed in the paths of the beams, was just the same, even though in the latter case, the intensities were cut down to the extent of about 50%. They showed that the two beams - primary and secondary - were equally absorbable. Beyond this critical value however, the ratio for the "intercepted" beams dropped very abruptly. This we have called the J_1-discontinuity - which corresponds to the discontinuity noticed in Barkla & Sale's absorption measurements (See Fig. 3 (a). It shows that the secondary beam began suddenly to exhibit greater absorbability. In many cases the ratio $\frac{I_s}{I_p}$ for the "intercepted" beams was found lower than the ratio $\frac{I_s}{I_p}$ for "unintercepted" beams, even before the critical absorption-coefficient had been reached. This was more frequently so, when the number of paper sheets used as radiator was considerable. This showed that the J_1-discontinuity - at any rate, the phenomenon associated with the J_1-discontinuity - must have already taken place; for the magnitude of the change was exactly that, which under other conditions, was seen to occur abruptly. In Table II. are given the values of the ratio $\frac{I_s}{I_p}$ for (1) "unintercepted" and (2) "intercepted" beams over quite a big range of wave-lengths of the primary beam. Results of experiments when thin and thick radiations were used, are given for comparison. Figures 3 (a) and 3 (b) represent these graphically. Table III. shows the abrupt drop in the ratio $\frac{I_s}{I_p}$ for "intercepted" beams, when a thick paper-radiator was used. Fig. 4 exhibits the same graphically. The results shown are only a few of a large number, exhibiting the same phenomenon.

After the J_1-discontinuity, the ratio $\frac{I_s}{I_p}$ for "intercepted" beams persisted at a constant value, until at a particular absorbability of the primary beam, there was observed a further drop -

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J_2- DISCONTINUITY :

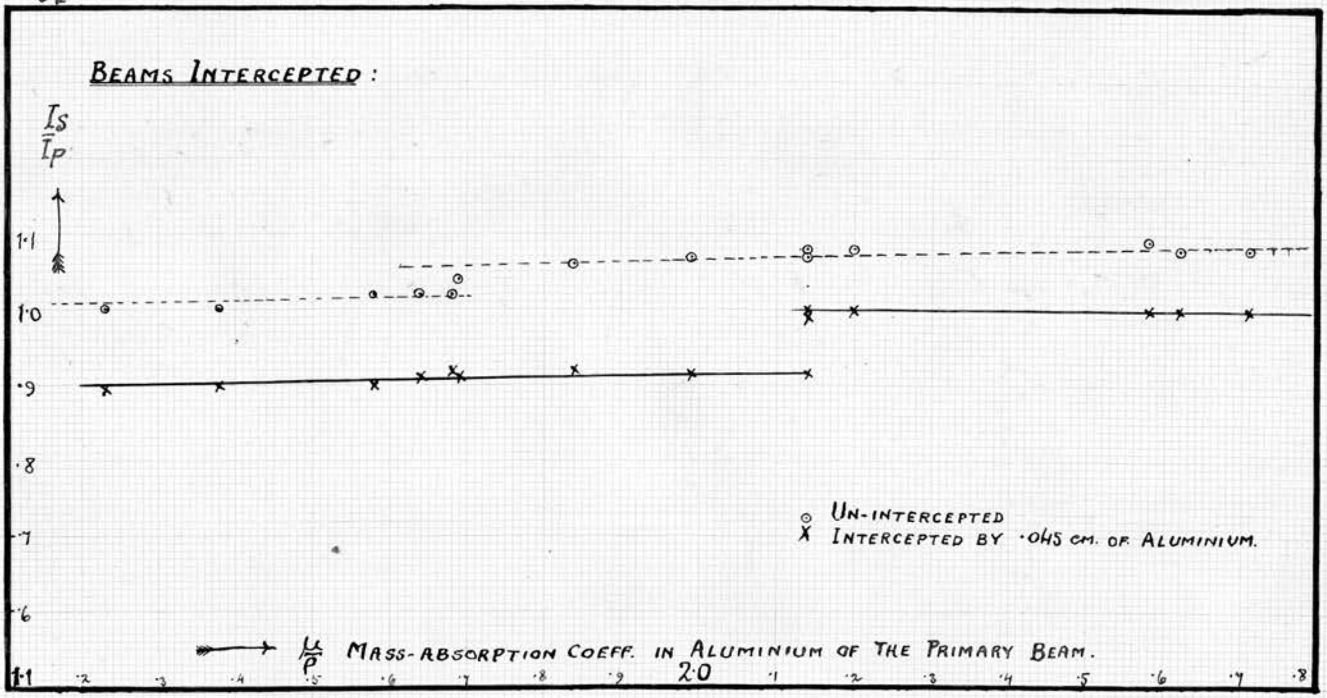

FIG 5(a)

J_2- DISCONTINUITY :

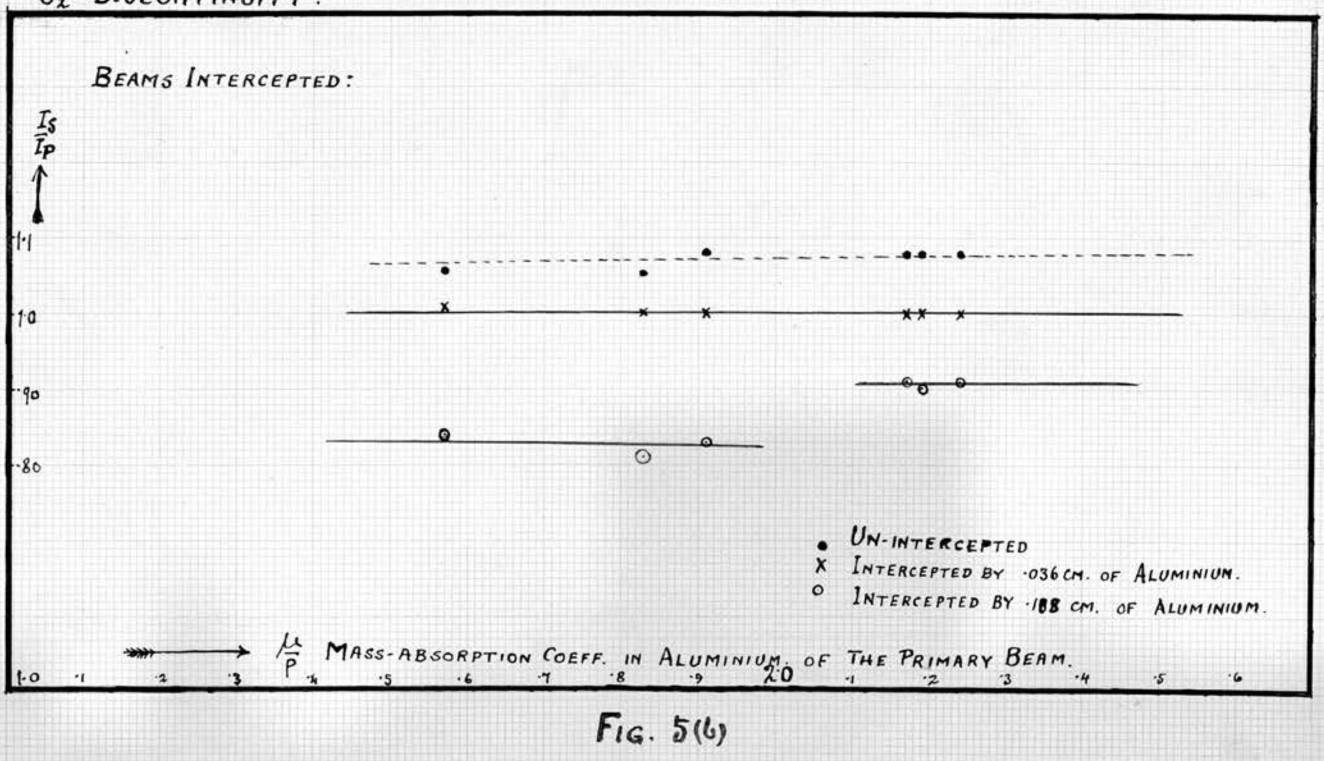

FIG. 5(b)

T A B L E IV.

J_2 - Discontinuity:

Tungsten Anticathode			Palladium Anticathode			
$\frac{\mu}{\rho}$	Observed ratio of intensities secondary and primary (arbitrary units)		$\frac{\mu}{\rho}$	Observed ratio of intensities secondary / primary. (arbitrary units)		
	Unintercepted	Intercepted by ·045 cm. of Al.		Unintercepted	Intercep. by ·036 cm. Al.	Intercepted by ·108 cm. of Al.
2.58	1.09 xx	1.00 xx				
1.99	1.07	.915				
2.20	1.08	1.00				
2.14	1.08	.915				
1.84	1.06	.920				
2.62	1.08	1.00	2.17	1.08 xy	1.00 xy	.910 xy
2.71	1.08	1.00	2.24	1.08	1.00	.910
2.14	1.07	.990	2.19	1.08	1.00	.900
1.69	1.04	.910	1.91	1.08	1.00	.830
1.64	1.02	.910	1.57	1.057	1.01	.840
1.58	1.02	.900	1.83	1.05	1.00	.810
1.38	1.00	.900				
1.23	1.00	.895				
1.68	1.02	.920				
2.14	1.03?	1.00				
	VIDE FIG. 5(a)				VIDE FIG. 5(b)	

J_3-DISCONTINUITY:

To face Fig. 16.

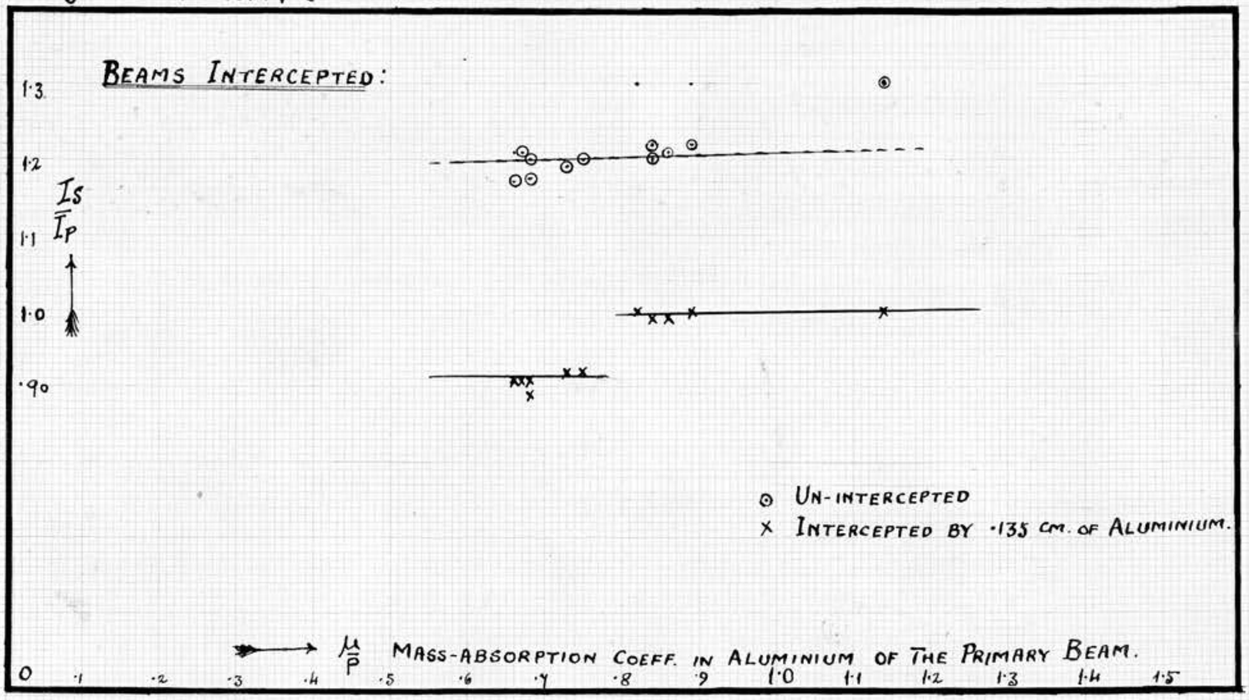

FIG. 6.

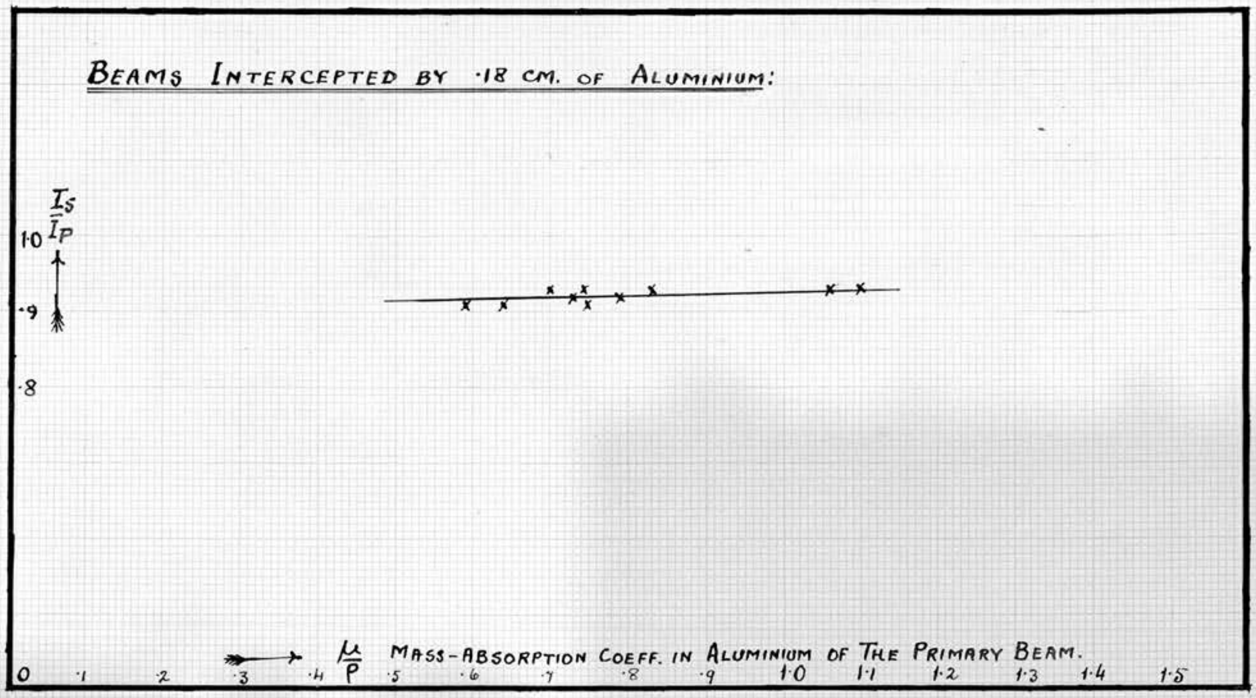

FIG. 7.

TABLE V.

L_3 - Discontinuity

$\frac{\mu}{\rho}$	Observed ratio of intensities secondary / primary. (in Arbitrary Units) Unintercepted	Intercepted by ·135 cm. of Al.	$\frac{\mu}{\rho}$	Observed ratio of intensities secondary / primary Unintercepted	Intercepted by ·18 cm of Al (In arbitrary units)
..14	1.30 ? xx	1.00 xx			
.68	1.175	.91			
84	1.20	.99	.59	..	.91 xy
.86	1.21	.99	.64	..	.91
.82	1.3?	1.00	.73	..	.92
.67	1.21	.91	.70	..	.93
.75	1.20	.92	.83	..	.93
.84	1.22	.99	.79	..	.92
.68	1.20	.89	.745	..	.93
.89	1.32) ? 1.22)	1.00) 1.00)	.748	..	.91
.73	1.19	.92	1.10	..	.93
.66	1.17	.91	1.06	..	.93
	VIDE FIG. 6.			VIDE FIG. 7.	

the J_2-discontinuity. This discontinuity was very seldom missed. Table IV. and figures 5 (a) and 5 (b) illustrate the J_2-discontinuity.

Table V. gives the values of $\frac{I_s}{I_p}$ when the primary and the secondary beams were intercepted by equal thicknesses of aluminium <u>at the hard end</u>. There was observed a further drop - the J_3-discontinuity. This was missed more than once. Figures 6 and 7 show the results, obtained when the discontinuity was observed and when it did not appear.

Indication of a fourth discontinuity has also been obtained. The experiments were not sufficiently careful or numerous to justify any very definite statement regarding it.

The positions of all these discontinuities for an <u>aluminium absorber</u> are given below:*

J_1-discontinuity.. $\frac{\mu}{\rho}$ in Al.= 3.8 (when the intercepting aluminium cuts off 50% of the primary radiations)
J_2-discontinuity.. $\frac{\mu}{\rho}$ in Al.= 1.9 " " " "
J_3-discontinuity.. $\frac{\mu}{\rho}$ in Al.= .76 (in these experiments, aluminium absorbed 20% of the primary radiations)

That these results were not due to any experimental error, was shown by the persistent occurence of these discontinuities, in spite of all precautions taken, in carrying out these experiments to guard against probable sources of error. The discontinuities were retraced quite a number of times, both with increasing and decreasing wavelengths. They appeared quite abruptly and very closely at the same penetrating power.

Precautions:

(a) It seemed not improbable that a narrow pencil of primary

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* The absorption-coefficient was obtained from the equation $I = I_0 e^{-\mu x}$ when the thickness x of absorbing aluminium was sufficient to make $I = \frac{1}{2} I_0$.

primary radiation, such as was received in the primary ionisation chamber, was not a true measure of the incident primary beam of considerable cross-section as it fell on the radiator. To avoid this uncertainty, the beam incident on the radiator was made as narrow as possible and a number of very small pinholes, ~~(instead of one)~~ evenly distributed over an area of the lead screen were used to ensure that a fairly representative bundle of the primary beam was obtained.

(b) Small apertures in the lead box were also necessary to guard against the effects of the superposition of the soft fluorescent radiations from the anticathode and from the glass of the X-ray tube. For, these oblique radiations would produce much greater proportional effects in the secondary electroscope than in the primary electroscope, the small apertures leading to the latter being comparatively long and narrow.

(c) For similar reasons, i.e. to avoid superposed fluorescent and scattered radiations, filtering sheets were rarely used in hardening the incident beam of X-rays. At the hard end, when on a few occasions, filters were used to harden the beam, they were always kept fixed throughout the experiment.

(d) The angle subtended at the window of the secondary ionisation chamber, by the aperture, transmitting the secondary beam, very near to the radiator was about 14°. Hence, in these experiments, the thickness of the absorber, traversed by <u>the most oblique rays possible</u> is greater than the normal thickness by about 3%. Taking a mean, the error due to the obliquity of the rays, could not exceed 1%.

(e) The absorbing sheets were kept as far away from the ionisation chamber as possible. The distance of the secondary ionisation chamber was 25 cm. away from the radiator; the absorbers were placed at a distance of about 7 to 9 cm. from the latter. The distance of the primary ionisation chamber was 44 cm. from the radiator. This was necessary to avoid the scattered and fluorescent radiation coming from the absorbers and affecting the ionisation in the chambers. (The small difference of paths of the primary and secondary beams through air, produces a quite negligible effect on the relative constitution of these beams. Indeed, the effect of absorption by air on either, is very small).

(f) Different X-ray tubes were tried, with anticathodes both of tungsten and of palladium. The discontinuities were quite independent of the tube or of the nature of the anticathode. The phenomena cannot therefore be due to any characteristic radiations from the target. This is shown in Tables IV. & XI. in which anticathodes of both substances were used. (See Figs. 5 (a) & 12)

(g) Stray effects, due to any possible extraneous radiation were looked for, especially in the region of the discontinuities. They showed no effect of the kind observed and thus cannot be held responsible for these discontinuities. See Table XIV (b).

Deductions from these Experiments: The significant fact in these experiments is that, the ratio of the "intensity" of the scattered beam to that of the primary beam, with and without the absorber in the path of both the secondary and primary beams, was exactly the same, in the region of longer wave-lengths. This leaves no doubt as to the exact equality in the penetrating powers of the secondary and the primary beams at the soft end. The maximum error of experiments was not more than 2% and the average indicated that the difference between the coefficients of absorption of secondary and primary radiations was certainly less than 1%. The close equality of penetrating powers, gives strong support to J.J.Thomson's classical theory of scattering.

It is also conclusive from these experiments that the discontinuities observed in the curve for the "intercepted" beams, have their origin not in the radiator at all, neither in the form of an emission of fluorescent radiation, nor in a change of wave-length in the process of scattering; because in either case, the transformation ought to have been detected in the curves for unintercepted beams, unless there happened to be exact compensation for increased absorbability by diminished intensity of the secondary radiation. Considering the accuracy of the experiments, this is expecting altogether too much from a coincidence! Further evidence is given later in the paper.

The appearance of these discontinuities after the interposition of the absorber, therefore, proves that they must be connected with some hitherto-unknown absorption phenomenon in the absorber interposed. The reduced value of $\frac{I_s}{I_p}$, beyond a critical absorption-coefficient of the primary beam, signifies a change in absorption-coefficient, either of the scattered or of the primary beam; but this change is not in the process of scattering. It is a subsequent phenomenon in the process of transmission through the absorber.

There is however, evidence for the belief, that in these experiments it is the scattered beam which behaves in such an anomalous way in transmission through matter. Barkla & White's experiments were done mostly with primary beams; and later experiments of Barkla, showing the absorption discontinuities ~~indicated~~ further that the discontinuity occurs more frequently with the scattered than with the primary beam.[1] The filtering experiments with the scattered beam, which will be described next, showed that in these experiments the scattered beam was responsible for this anomalous

1. Barkla, Silvanius Thomson Memorial Lecture April 1, 1924.

behaviour in transmission through ~~transmission through~~ matter.

These results therefore, contradict A.H. Compton's theory of a change in wave-length, in the process of scattering by quanta. The difference observed at the penetrating end, (and sometimes at the soft end too) in the absorption coefficients of the primary and the secondary beams, is not due to any change in wavelength of the incident beam on scattering. It is due, as shown above, to a subsequent process, linked up with an entirely new absorption phenomenon, which we have conveniently called the "J"-phenomenon.

An examination of the horizontal lines in Fig. 3 shows that the equality in the ratio $\frac{I_s}{I_p}$ for both "intercepted" and "unintercepted" beams, does not always appear, even at the soft end. It appears that there are some critical conditions which are connected with the "J"-absorption effect. It is premature to make any definite assertion, concerning these conditions, at the present stage of our knowledge. Some possibilities will be considered later.

It is very interesting to notice that Barkla & White's discontinuity, in their absorption experiments on primary beams, corresponds with the J_3-discontinuity. The wave-lengths of the rays, in the regions of their discontinuities, obtained from the known relation between the wave-length and absorption in aluminium, were given approximately as follows:

C....0.42 x 10^{-8} cm.

C....0.39 x 10^{-8} cm.

Al....0.37 x 10^{-8} cm.

Dauvillier's discontinuities* appeared at .358 Å in aluminium and

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* Dauvillier used Methyl iodide in his ionisation chambers. Richt-

at .227 Å in Bromine.

The discontinuities observed by Barkla in the ionisation experiments (<u>using characteristic radiation</u>) correspond most probably with the J_2-discontinuity. The discontinuity in the corpuscular emission by aluminium appeared, when $\frac{\mu}{\rho}$ = 1.9, and that in air appeared, when $\frac{\mu}{\rho}$ = 2.5 nearly. Discontinuities, observed in Williams' absorption experiments with homogeneous radiations, obtained by using a spectroscope, appeared in aluminium at .49 Å, and in copper at .448 Å. They are, almost certainly, identical with the J_2-discontinuity. (.49 Å corresponds to a value of $\frac{\mu}{\rho}$ in aluminium, of about 2).

Owen's observation of a sudden increase in absorption seems to correspond with the same. He studied the spectrum of the rays coming from a palladium anticathode, obtained by reflection from the (III) face of a carborundum crystal. The spectrum showed a minimum of intensity, at a certain value of the glancing angle, corresponding to a wave-length of .493 x 10^{-8} cm. It should be noted, that one of the atoms comprising the crystal is Silicon, which is lower than aluminium by only one atomic number. The fourth discontinuity, (say the J_4-discontinuity) which was observed in experiments with still harder radiations, can be identified with the I-discontinuity observed by Barkla & White.

<u>Experiments III</u>

<u>Effect of transmission of a secondary beam through matter.</u>

(The Filtering of the Secondary Beam alone).

As the discontinuity appeared at a certain critical hardness, a question arose as to whether heterogeneous beams would show the discontinuity, when filtered and made to pass through that critical

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Richtmyer suggested that his discontinuity in aluminium at .358 Å might be due to the K-line of iodine. He further points out that Dauvillier's discontinuity for Bromine might be explained by Duane's α_3-line of tungsten. Richtmyer's remarks. Phys. Rev. July, 1921.

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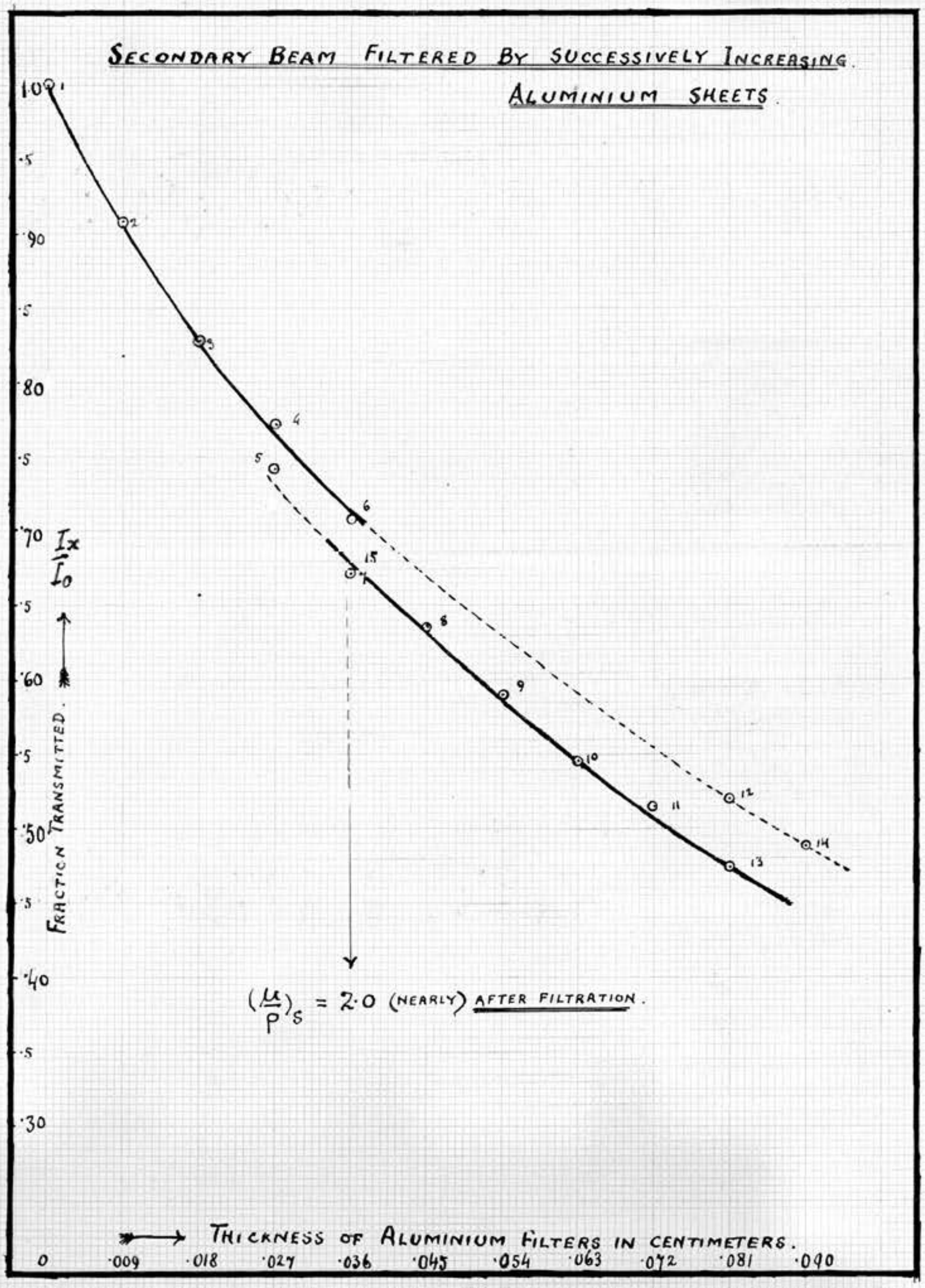

FIG. 8.

TABLE VI.

Secondary Beam

No.	Number of Thickness of Aluminium Filters	Fraction transmitted $\frac{I_x}{I_o}$
1	0	1.00
2	.009 cm.	.909
3	.018 ..	.828
4	.027"	.772
		.742
5	.036 "	.707
		.671
6	.045 "	.636
7	.054 "	.590
8	.063 "	.545
9	.072 "	.515
10	.081 "	.520
		.474
11	.090 "	.489
12	.036 "	.671
13	.027 "	.772
14	.036 "	.712

VIDE FIG. 8.

region in the average penetrating power. The secondary beam from paper sheets, was therefore filtered successively by aluminium sheets of equal thickness. The fraction of the original secondary beam, transmitted through each successive sheet was measured (by the ionisation, produced in an electroscope) and plotted against the thickness of the aluminium filters. The unintercepted primary beam was used as a standard. The intensity of the beam was found to diminish quite regularly with the thickness of the aluminium sheets up to a certain thickness at which the absorption exhibited a sudden rise. The order of the experiment was reversed, the thickness of the absorbing material being diminished and the discontinuity was again observed; but of course, in the opposite sense. This was repeated a number of times. Table VI and Fig. 8 give one of many sets of experimental results. The mass absorption-coefficient of the beam in aluminium after filtration through the critical thickness at which the discontinuity occurred was about 2 when measured in the same way as in the previous experiments.* This corresponds closely with the critical absorption coefficient for the J_1-discontinuity as found by experiments, previously described. (Table IV Fig. 5). This shows the connection between the two results and throws great light on the cause and nature of these discontinuities.

Deductions from these experiments: The results show that, at a particular hardness of the beam, the absorption in a thin layer of the absorbing substance increased enormously. Since, in these experiments a heterogeneous beam was used, the effect of successively filtering the secondary beam is presumably only to harden the beam, by altering the proportion of the constitutients. In gradually

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* cutting off 50%

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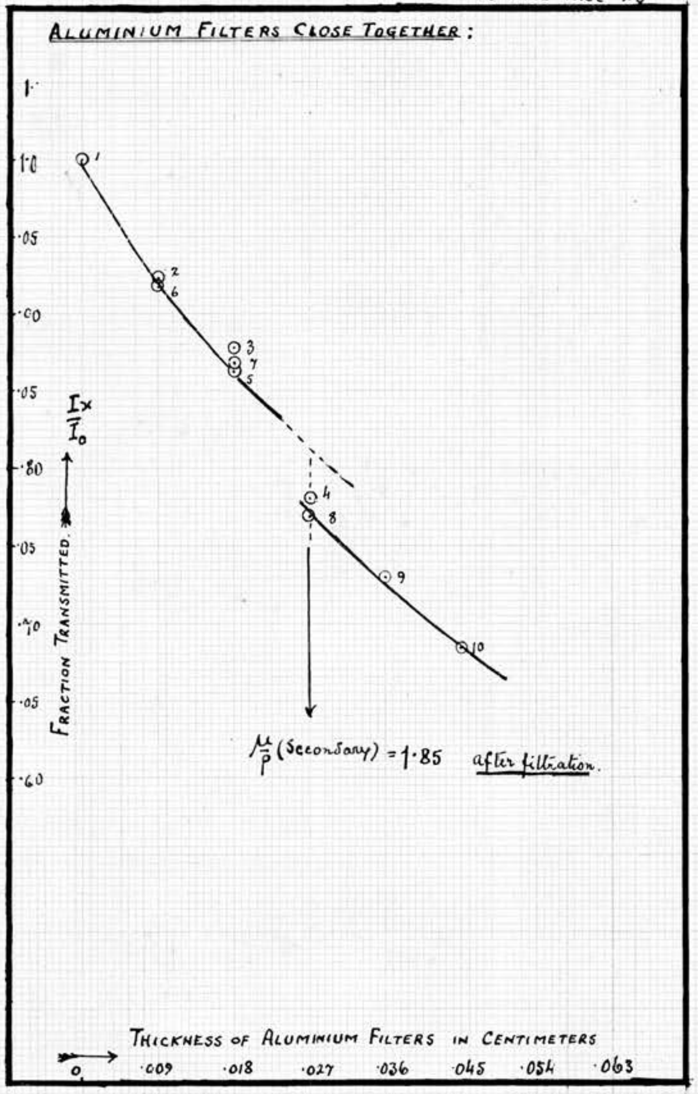

FIG. 9(a)

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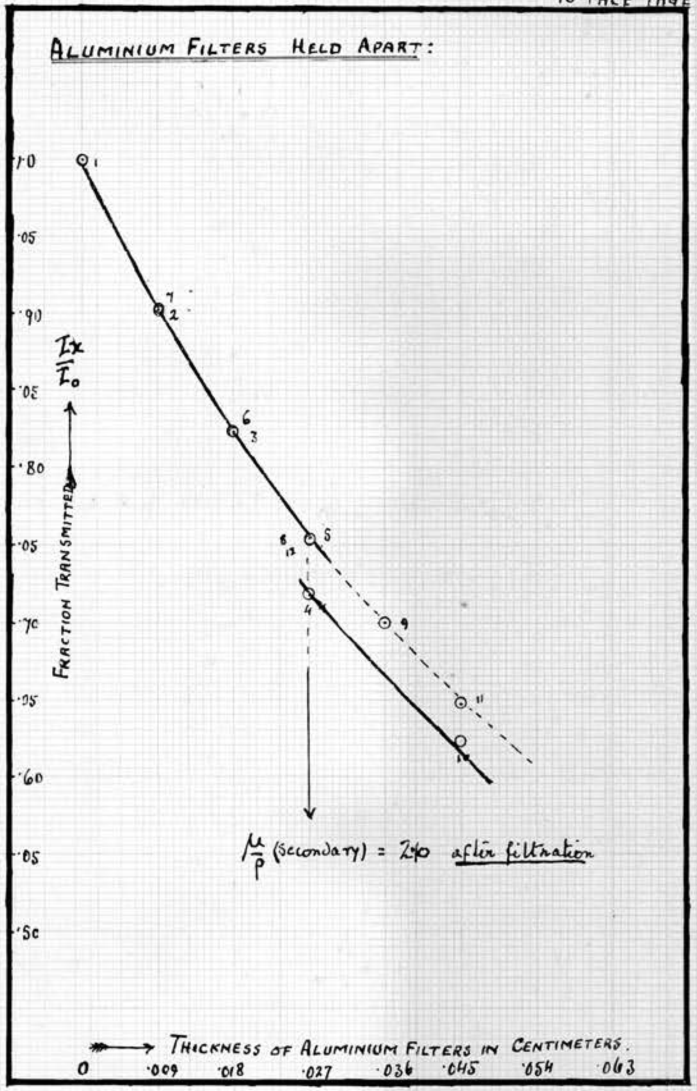

FIG. 9(b)

TABLE VII.

A. Aluminium Filters close together:

No.	Thickness of Aluminium Filters	Fraction transmitted $\frac{I_x}{I_o}$
1	.00	1.00
2	.009 cm.	.923
3	.018 "	.878
4	.027 "	.780
5	.018 "	.862
6	.009 "	.917
7	.018 "	.868
8	.027 "	.769
9	.036 "	.730
10	.045 "	.684

Vide Fig. 9(a).

TABLE VIII

B. Aluminium Filters held apart:

No.	Thickness of Aluminium Filters	Fraction transmitted $\frac{I_x}{I_o}$
1	.00 cm.	1.00
2	.009 "	.902
3	.018 "	.821
4	.027 "	.718
5	.027 "	.754
6	.018 "	.823
7	.009 "	.904
8	.027 "	.754
9	.036 "	.700
10	.045 "	.622
11	.045 "	.647
12	.027 "	.754

Vide Fig. 9(b)

hardening the beam in this way, when the critical hardness was attained, a large absorption took place in the first layer of the aluminium which was exposed to the beam of that particular hardness. The subsequent slope of the curve, as shown in Fig. 8 does not definitely show, if there is a change in the absorbability, subsequent to the discontinuity. The rate of absorption seems to be very nearly the same as before the discontinuity, the curves before and after the break running almost parallel to each other. (But there is decided evidence from other experiments that the absorbability of the beam in that substance is slightly increased after this big absorption).

It seemed possible that the sudden increase in the absorption, although precipitated by a thin sheet was in reality the effect of the whole absorbing material,— indeed, that although thelast thin layer was necessary, the increased absorption did not take place in it alone, but in the whole body of the absorbing substance. This was suggested by the possibility of a transfer of energy from atom to atom in the absorbing substance. Such transfer might bring the atoms of the earlier layers into a critical absorbing state. That this is not so, was proved in two ways:

(1) The successive aluminium sheets were kept at some distance apart from one another. The discontinuity however, occurred still at the same place and with an unchanged magnitude. Tables VII & VIII with Figs. 9 (a) and 9 (b) show these results.

(2) If the sudden increase in absorption was throughout the body of the absorber, the magnitude of the change in absorption would depend on the total thickness of the absorbing sheets. The state of the X-ray tube was so arranged that the scattered beam would

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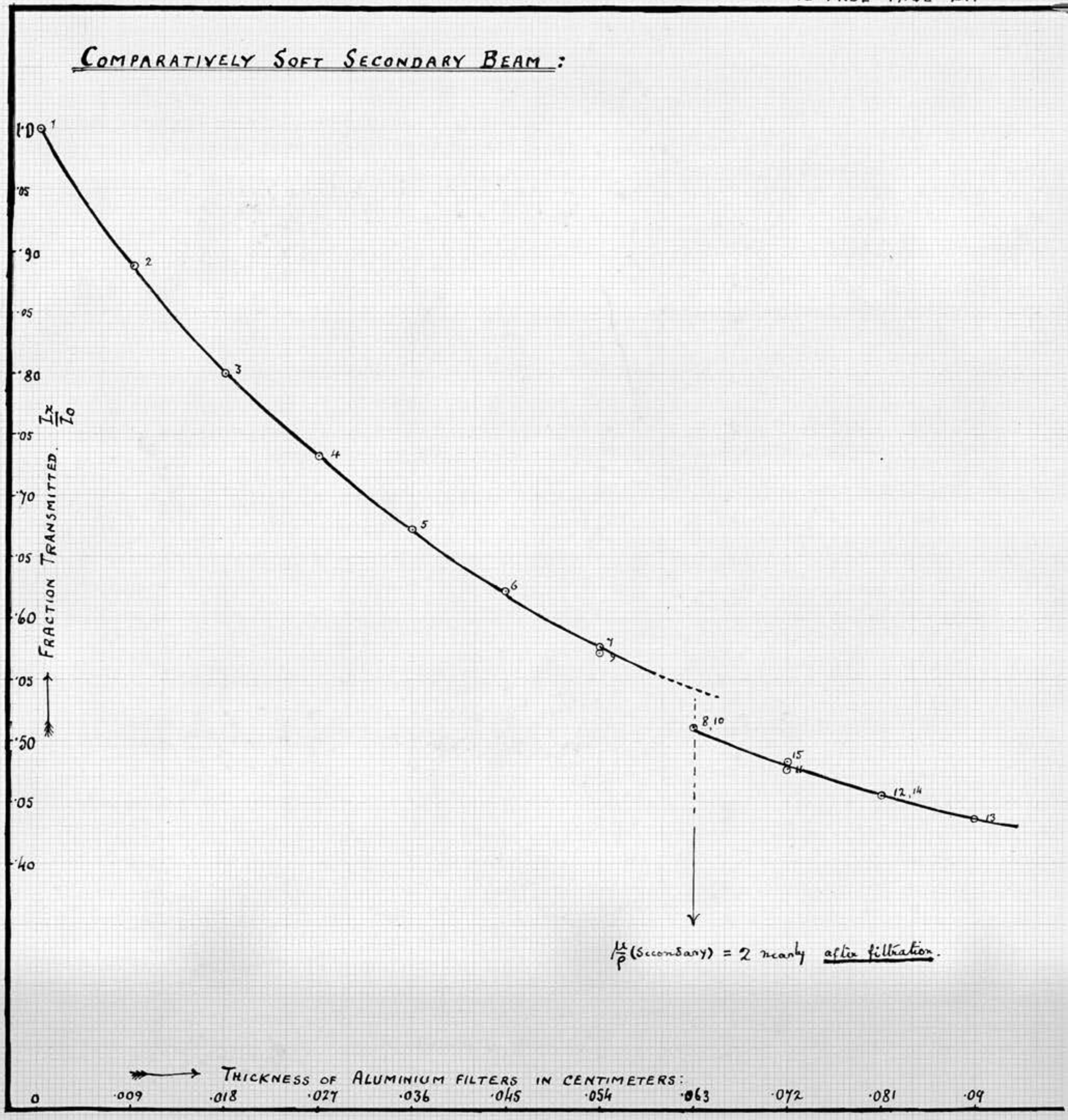

FIG. 10.

TABLE IX.

Comparatively soft beam of scattered rays

No.	Thickness of Alum. Filter.	Fraction Transmitted $\frac{I_x}{I_o}$
1	0.00 cm.	1.00
2	.009 "	.888
3	.018 "	.800
4	.027 "	.733
5	.036 "	.672
6	.045 "	.622
7	.054 "	.577
8	.063 "	.511
9	.054 "	.572
10	.063 "	.511
11	.072 "	.477
12	.081 "	.455
13	.090 "	.436
14	.081 "	.455
15	.072 "	.483

VIDE FIG. 10

attain the critical hardness after being filtered through one or two of the thinnest sheets of aluminium. On successively filtering the scattered beam, the discontinuity was obtained. A similar filtering experiment was made with a comparatively soft scattered beam, so soft that a fairly thick sheet of aluminium was required to harden the original beam to the critical value. The magnitude of the rise in absorption was, within the limits of experimental error, the same in the two cases. This is contradictory to the supposition that the rise in absorption is throughout the body of the absorber. Table IX with Fig. 10 shows the result of experiments with the comparatively soft beam of scattered rays. Figs. 9 (a) and 9 (b) should be compared with Fig. 10.

The observed large and anomalous absorption is strongly confirmed by Barkla & White's experiments on ionisation and corpuscular radiation, some of which are described in the Bakerian lecture[1] for 1916 and many of which are yet unpublished.[2] In their experiments they obtained a large increase (in some cases more than 100%) in ionisation in air and SO_2 and also in the corpuscular emission from aluminium. The critical absorption coefficient at which there was a change in the corpuscular emission from aluminium in the experiments of Barkla & White, agrees remarkably with the critical value at which the discontinuity has been observed in these filtering Experiments. The change appeared in the corpuscular emission from aluminium when $\left(\frac{\mu}{\rho}\right)_{al} = 1.9$.

To determine whether at the point of discontinuity, there is a

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1. Bakerian Lecture Trans. Roy. Soc. Lon. Ser. A. Vol. 217.

2. White - Ph. D. Thesis 1921. Edin. Univ.

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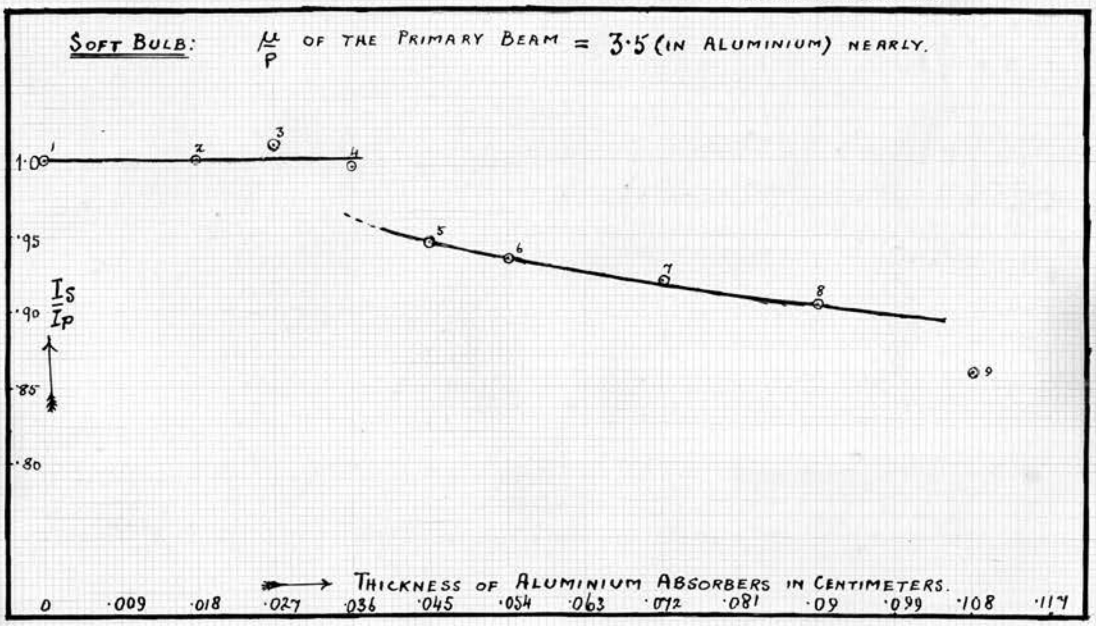

FIG 11(a)

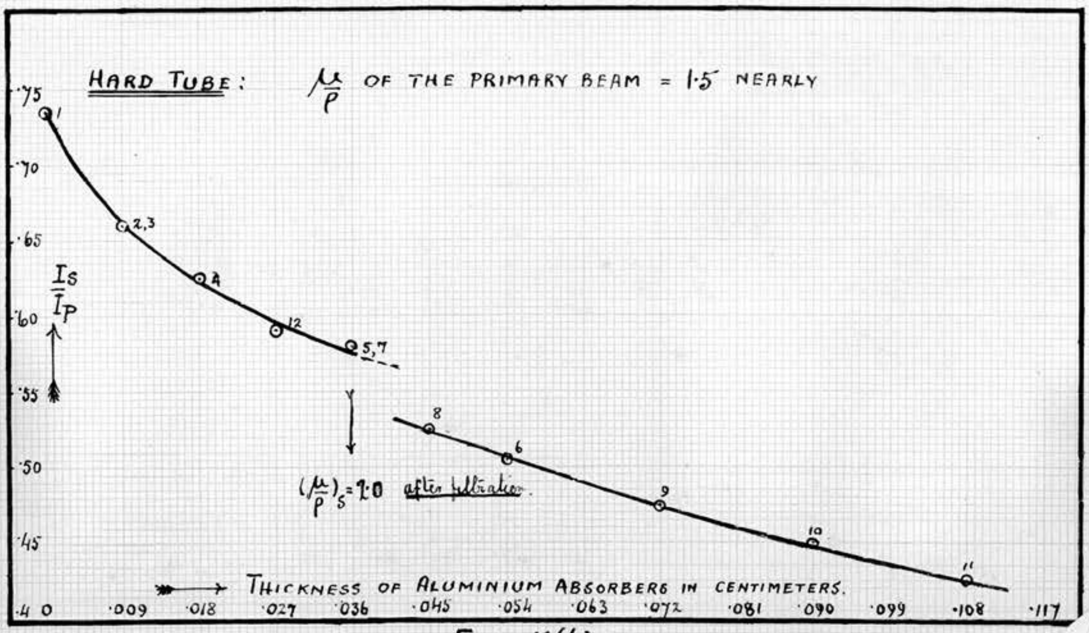

FIG 11(b)

TABLE X

No.	Soft tube: $\frac{\mu}{\rho} = 3$ to 3.5 — Thickness of Alum.	Observed Ratio $\frac{I_s}{I_p}$ in arbitrary units	Hard tube: $\frac{\mu}{\rho} = 1.5$ nearly — Thickness of Al.	Observed Ratio $\frac{I_s}{I_p}$ (in arbitrary units)
1	0.0 cm.	1.00 xx	0.0 cm.	.735 xy.
2	.018 "	1.00	.009 "	.660
3	.027 "	1.01	.009 "	.660
4	.036 "	.995	.018 "	.625
5	.045 "	.945	.036 "	.580
6	.054 "	.935	.054 "	.505
7	.072 "	.920	.036 "	.575
8	.09 "	.905	.045 "	.525
9	.108 "	.860	.072 "	.475
10	..	..	.090 "	.450
11	..	..	.108 "	.425
12	..	..	.027 "	.590

VIDE FIGS. 11(a) & 11(b)

real change in of wave-length of the radiations or not, during transmission, experiments are in progress, which it is hoped, will lead to a definite conclusion. Although the evidence, hitherto obtained, of a change in wave-length during transmission, is not very satisfactory, there is direct evidence of a change in the absorbability, in the substance, in which the discontinuity has been observed. The next set of experiments shows this most convincingly.

Experiments IV.

(The Filtering of Primary and Secondary beams simultaneously.)

In these experiments, primary and secondary beams were filtered by the successively increasing equal thicknesses of aluminium. The ratio $\frac{I_s}{I_p}$ of the "intensities" of the secondary and primary beams was measured, after both the beams had passed through gradually increasing equal sheets of aluminium. The values of the observed ratio, are plotted against the thicknesses of the aluminium filters.

Experiments were made for two different states of the X-ray tube; first, when the tube was fairly soft, giving out rays in the neighbourhood of the J_1-discontinuity; and secondly, when the tube was comparatively hard, emitting radiations, in the region of the J_2-discontinuity. In Table X. are tabulated the results of these two experiments. Figures 11 (a) & 11 (b) represent the same graphically.

Fig. 11 (a) clearly shows that, for soft radiations, the ratio $\frac{I_s}{I_p}$ is independent of the thickness of the filters, for a certain range, thus proving beyond doubt that, when thin absorbing substances are used, the absorbabilities of the primary and the secondary beams are just the same,* the experimental error being less than 1%. After a certain thickness, there is a sudden diminution of 5 to 6% of the ratio $\frac{I_s}{I_p}$ and then there is a steady falling off of the ratio. Fig. 11 (b) reveals another sudden change in the ratio of $\frac{I_s}{I_p}$ by about 6%. The mass-absorption coefficient of the secondary beam, after being filtered through the critical thickness, at which the second discontinuity appeared, was about 2 in aluminium**.

Deductions from these experiments:

These results show that, with soft radiations, there is, under the conditions of these experiments - exact similarity between the primary and secondary radiations, when thin sheets are used to measure the absorbabilities; but a difference appears with thicker absorbing sheets. They also clearly show, how an "unmodified" scattered radiation is suddenly transformed into a "modified" radiation, by simply filtering the "unmodified" scattered radiations, until the thickness of the absorber attains a certain value, (in the experiment, the results of which are shown in Table X, the critical thickness was .045 cm.) - thus proving conclusively that in these experiments at any rate, the transformation is not in the scattering substance, either in the form of an emission of a fluorescent radiation or in a change of wave-length in the process of scattering. The apparent change in the character of the scattered radiation is therefore unquestionably connected with a peculiar absorption phenomenon - the J-phenomenon. The curves in Fig. 11 (a) & 11 (b) show the

* These confirmed some fragmentary results obtained by Mrs. Sale. These were left unpublished as they awaited confirmation.

** Similar experiments were made by J.A. Crowther (Phil.Mag. 42,1921) and later by J.A. Gray (Proc. & Trans. of Roy. Soc. of Canada 1922, Sec. 3). Their curves did not show any of these peculiarities. Gray used a soft beam, $\frac{\mu}{\rho}$ being about 3 in aluminium; but unfortunately the filters he used were very thick; the mass in gms. per cm². of the thinnest sheet was .304, i.e. about .11 cm. and the thicknest filter weighed 1.216 gms. per cm². and was about .45 cm. thick. Crowther's aluminium filters, were also fairly thick. It is possible that this is the reason that Gray found the change in the ratio to start with.

characteristics of this J-absorption phenomenon, quite independently of the information obtained from the Experiments (No. II) with "intercepted" beams and the filtering experiments (No. III) with the scattered beam alone. These characteristics are:

(1) a large absorption, in a thin layer of matter at a certain value of the absorbability of the beam (as usually measured) and

(2) a slight increase in the absorbability of the transmitted beam, subsequent to this big absorption. (Whether this rise in absorbability, is a rise in that particular substance alone, or in all other substances, is a subject for further investigation).

<u>The positions of the discontinuities</u>: The J-discontinuities in Experiments No II. take place at fairly definite values for the average absorbability of the primary beam. When the intercepting aluminium cut off 50% of the primary radiations, the J_1 and J_2 - discontinuities appeared, when the mass-absorption coefficients (in aluminium) of the primary radiation were 3.8 and 1.9 respectively. The J_3-discontinuity appeared when $\frac{\mu}{\rho}$ = .76 nearly.

The positions depend, somewhat on the thickness of the absorbing sheets, placed in the path of both the primary and the secondary beams in these experiments. When the thickness of aluminium was sufficient to cut off 50% or so, of the primary radiations in the region of the J_1 -discontinuity, the position of the latter, as has already been stated, was given by $\frac{\mu}{\rho}$ in Al. = 3.8. On the other hand, evidence has been obtained that the J_1 -discontinuity appears a little shifted towards the hard end, when a thin absorbing sheet, cutting down about 20% of the radiations isused. Fig. 11 (a) illustrates this point quite clearly. Even though in this experiment, the

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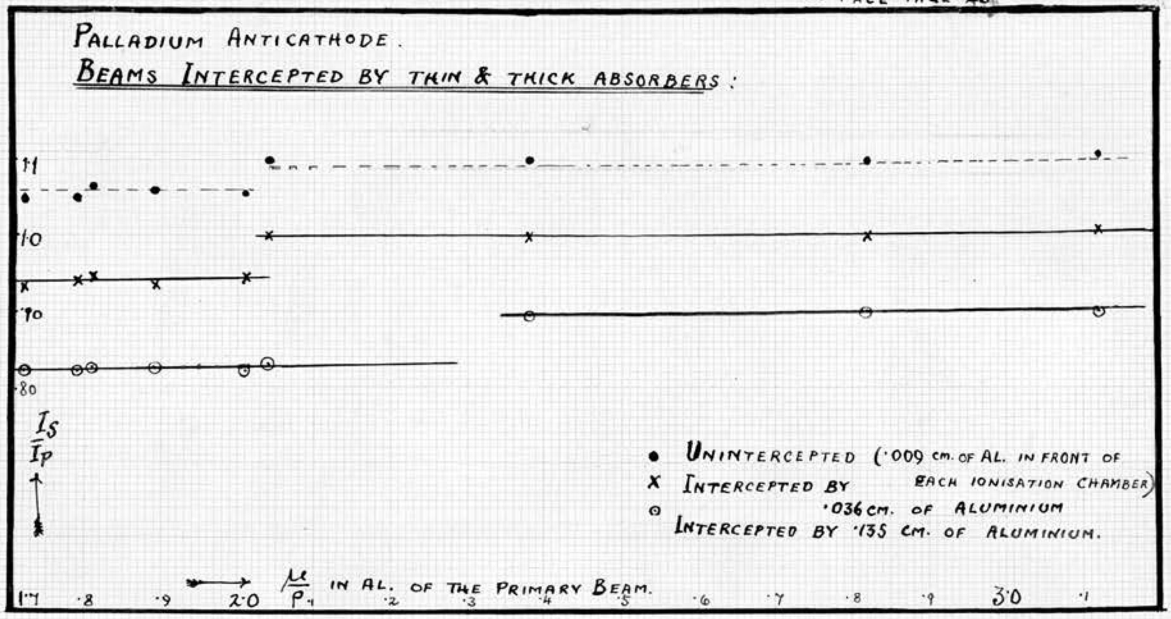

FIG. 12.

TABLE XI

Palladium Anticathode:

	In arbitrary units. Observed ratio of intensities, Secondary / primary		
Primary	Unintercepted x = .009 cm.	Intercep. by .036 cm.	Intercep.by
2.38	1.10 x x	1.00 x x	.895
2.82	1.10	1.00	.900
3.12	1.11	1.01	.900
2.38	1.10	1.00	.890
2.04	1.10	1.00	.830
2.01	1.055	.945	.820
1.81	1.065	.945	.825
1.79	1.050	.940	.820
1.89	1.060	.935	.825
1.72	1.050	.930	.820

mass-absorption coefficient of the beam, in aluminium, was a little less than 3.5, it is found that the ratio $\frac{I_s}{I_p}$ when the beams were intercepted by thin sheets of aluminium, was exactly equal to the ratio $\frac{I_s}{I_p}$ when the beams were unintercepted. This shows that the J_1-discontinuity had not taken place, in the thin absorbing material, even though the beam was slightly past the critical point, found with the thicker sheets. A similar shift of position was observed, also in the case of the J_2-discontinuity. Fig. 12 shows that, as the beam was hardened, the J_2-discontinuity appeared when the thick absorber was used, though it was not found with the thin absorber. Table XI gives the values of $\frac{I_s}{I_p}$ in the region of the J_2-discontinuity, when the primary and secondary beams were passed through thin and thick absorbing substances for various absorbabilities of the primary beam. These results however, are quite consistent, because when thicker absorbing sheets were used, the first layers, brought the heterogeneous radiations to the critical absorbability and the later layers produced the discontinuity.

The shift of position with the thickness of the absorbing material is entirely dependent on the heterogeneity of the X-radiations. If the beam were strictly homogeneous, the discontinuity should, of course, appear in the same position for any given absorbing element.

<u>The magnitude of the absorption steps</u>: The percentage fall in the ratio $\frac{I_s}{I_p}$ when the primary and secondary beams are intercepted by an absorbing material, has been seen to depend on the thickness of the latter. This is illustrated in Figs. 11 (a) & 11 (b). It is evident that there are two effects (1) a large absorption

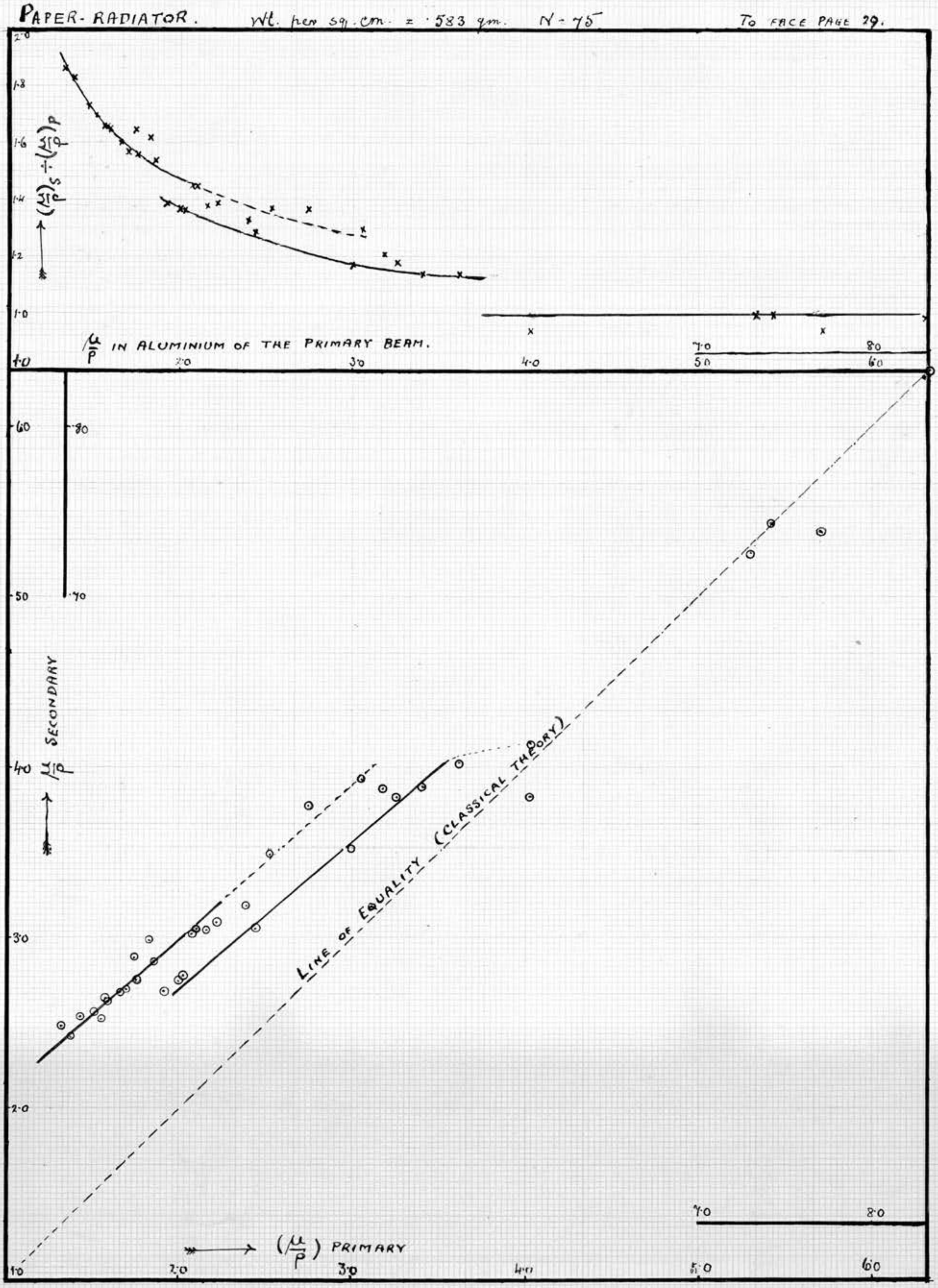
PAPER-RADIATOR. Wt. per sq. cm. = ·583 gm. N - 75
TO FACE PAGE 29.
$(\frac{\mu}{\rho})_S \div (\frac{\mu}{\rho})_P$
$\frac{\mu}{\rho}$ IN ALUMINIUM OF THE PRIMARY BEAM.
$\frac{\mu}{\rho}$ SECONDARY
LINE OF EQUALITY (CLASSICAL THEORY)
$(\frac{\mu}{\rho})$ PRIMARY

FIG. 13.

TABLE XII (a)

EIGHT OF PAPER RADIATOR PER SQ. CM. = ·583 gm. NUMBER OF SHEETS = 75

μ_p/ρ Primary	μ_s/ρ Secondary	$\delta\left(\frac{\mu}{\rho}\right) = \frac{\mu_s}{\rho} - \frac{\mu_p}{\rho}$		$\frac{\mu_s}{\rho} \div \frac{\mu_p}{\rho}$	
1.332	2.481	1.149		1.86	
1.385	2.417	1.132		1.83	
1.469	2.537	1.078		1.73	
1.510	2.566	1.056		1.70	
1.560	2.523	.963		1.66	
1.577	- 2.646	1.066		1.67	
1.587	2.623	1.036		1.65	
1.667	2.675	1.008		1.60	
1.706	2.695	.989		1.57	
1.746	2.882	1.136		1.65	
1.754	2.75	.998		1.56	
1.834	2.980	1.146		1.62	
1.857	2.866	1.009		1.54	
1.920	2.683		.763		1.39
2.002	2.740		.744		1.37
2.029	2.772		.743		1.366
2.075	3.021	.946		1.45	
2.099	3.058	.959		1.45	
2.16	3.043		.883 ?		1.38?
2.221	3.091		.870?		1.39?
2.395	3.187		.792		1.33
2.439	3.048		.609		1.29
2.529	3.489	.960		1.37	
2.748	3.775	1.027		1.37	
3.002	3.528		.526		1.170
3.063	3.986	.923		1.30	
3.184	3.870		.686		1.21
3.41	3.882		.742		1.14
3.627	4.035		.408		1.14
4.038	3.82			·94	$\boxed{1.00}$
5.678	5.38			·94	$\boxed{1.00}$

TABLE XII (b)

Weight in gms. of paper sheets as radiator = ·583 gm. per cm. sq.
N = 75

Primary μ_p/ρ	Secondary μ_s/ρ	$\frac{\mu_s}{\rho} \div \frac{\mu_p}{\rho}$
3.26	3.83	1·18
4.03	4.14	1·02
5.33	5.26	·98
7.43	7.42	1·00
8.34	8.27	·99

in a thin layer of the absorbing material and (2) a slight increase in the absorbability of the beam, subsequent to the large absorption. These two, determine the total fall in the ratio of I_S/I_P when the beams are intercepted by any absorbing material; the first part is independent of the thickness of the absorber and the second part appears to vary approximately exponentially with the thickness of the absorbers. (This exponential relation could not be tested with any accuracy, as the beam was heterogeneous).

As a result of these two effects, the magnitude of the absorption steps, appears to be fairly large even when the absorbing material is very thin.

When the intercepting aluminium cuts off about 50%, in the neighbourhood of the discontinuities, the percentage magnitudes of the absorption steps (in aluminium) are given below:

(1) J_1 - discontinuity 12%
(2) J_2 - discontinuity 10%
(3) J_3 - discontinuity .... 8% (when the intercepting aluminium cuts off about 20%.)

It would be unwise, to base any conclusions upon results of this kind, for it is quite possible, indeed probable, that the observed magnitudes are not so simple as, at first sight, they may appear. Complications may very well arise, owing to phenomenon of exactly the same nature, as those occuring in the absorbor, taking place in the gas in the ionisation chamber.

Experiments V.

(Direct comparison of the Penetrating powers of the Secondary and Primary Beams)

In view of what has been shown, regarding the nature of the J - absorption phenomenon, it is evident that absorption-coefficients as determined in the usual way from the equation

$$I = I_0 . e^{-\mu x}$$

ceases to have any definite meaning; for the exponential law completely breaks down. This law however, holds in the absence of any such discontinuity; and it is interesting to see the effect of the phenomenon, on the relations between the absorption-coefficients, (as usually measured) of the primary and secondary radiations.

Thus, the absorption-coefficients of the primary and secondary beams were simultaneously measured, using a third electroscope as a constant standard.

Particular care was taken to cut off 50% of the radiation as nearly as possible, in measuring the absorption-coefficients. Errors in the values of $\frac{\mu}{\rho}$ due to heterogeneity of the beam were thus avoided. The same thickness was not used to measure the co-efficients of absorption of the primary and secondary beams.

The results of these experiments are in agreement with what the above results would lead us to expect. There is equality in the penetrating powers of the secondary and primary beams at the soft end, (See Fig. 13). The equality is obtained more frequently with thin radiator than with thick. (Barkla & Sale's experiments

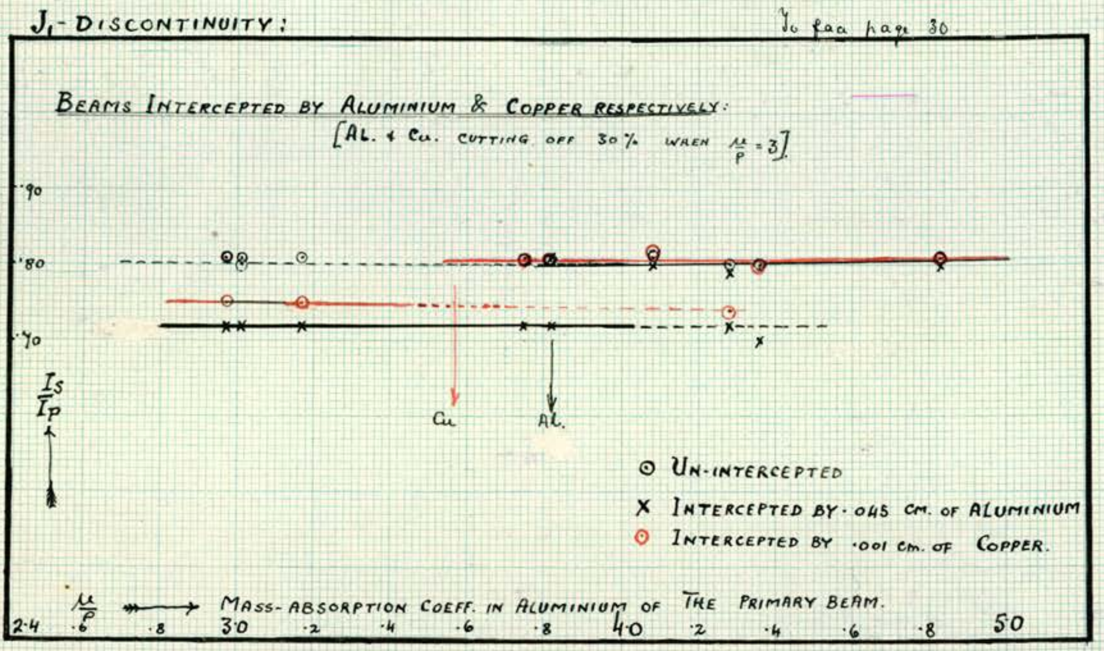

FIG 14 (a)

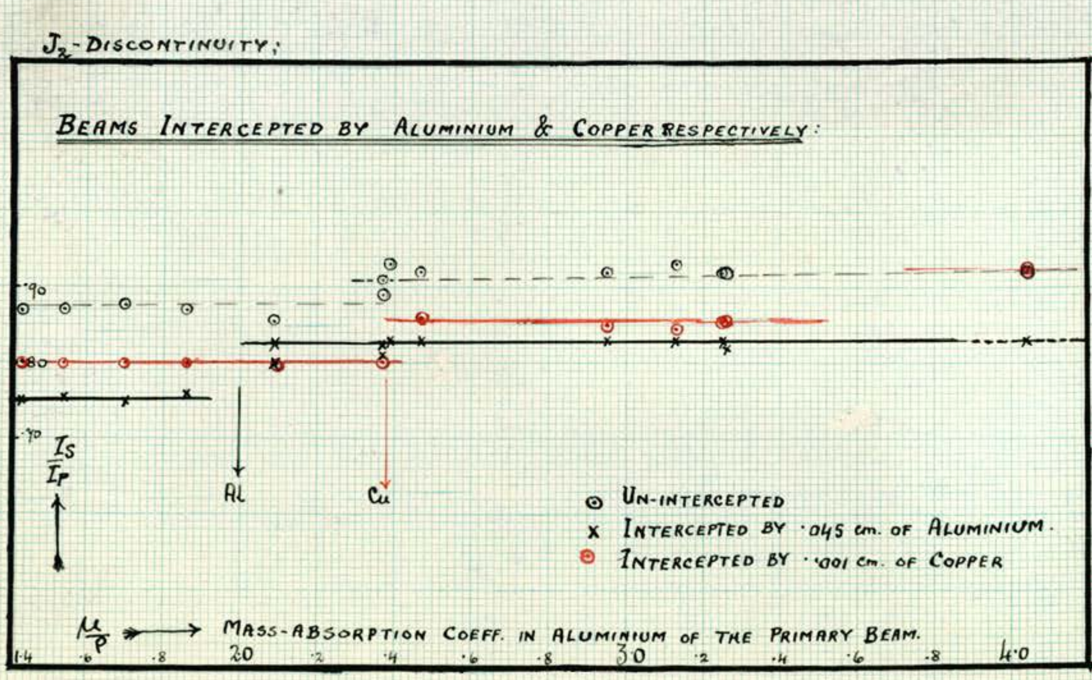

FIG 14 (b)

TABLE XIII

J_1 - Discontinuity :

$\frac{\mu}{\rho}$ Primary	Observed ratio of intensities $\frac{I_S}{I_P}$ in arbitrary units		
	Unintercepted	Aluminium x = .045 cm.	Copper x = .001 cm.
3.01 (approx)	.80 xx	.72 xx	..
4.28	.80	.79) .72)	.74 xx
4.83	.81	.80	.81
3.82	.805	.72	.80
4.08	.81	.80	.82
4.36	.80	.70	.80
3.01	.81	.72	..
3.82	.81	.81	.81
3.17	.81	.72	.75
2.97	.81	.72	.75
3.75	.81	.72	.81

VIDE FIG. 14(a)

J_2 - Discontinuity : Copper and alum.cutting off 30% when $\frac{\mu}{\rho}$ = 3 nearly

3.25	.92 xy	.830 xy	.855 xy
3.26	.92	.82	.855
2.39	.93	.83	.83
3.13	.93	.83	.845
2.47	.92	.83	.860
4.04	.92	.83	.925
2.95	.92	.83	.850
2.37	.91) .89)	.825) .810)	.800
2.09	.855	.825) .800)	.800
1.83	.87	.760	.800
1.70	.875	.75	.800
1.54	.87	.755	.800
1.43	.87	.75	.800

VIDE FIG. 14(b)-

TABLE XIV. (a)

Set I.	Paper and aluminium cutting off 30% when $\frac{\mu}{\rho}$ = 2 nearly		
$\frac{\mu}{\rho}$ Primary	Unintercepted Observed ratio $\frac{I_s}{I_P}$ (In arbitrary units)	Aluminium x = .063 cm. Observed ratio $\frac{I_s}{I_P}$ (In arbitrary units)	130 sheets of pap Observed ratio $\frac{I_s}{I_P}$ (In arbitrary units)
2.07	1.03 xx	.92 xx	.95 xx
2.00	1.03	.92	.95
1.91	1.03	.90	.95
1.79	1.02	.90	.895
1.77	1.00	.83	.905
1.58	1.00	.83	.89
2.28	1.035	.915	.95
2.08	1.03	.92	.96
2.06	1.02	.92	.955
2.23	1.02	.91	.96
1.86	1.02	.90	.905) .95)
1.85	1.01	.895	.90) .895)
1.70	.97	.835	.90

TABLE XIV (b)

Set II.	Aluminium and Paper cutting off 50% when $\frac{\mu}{\rho}$ = 2 nearly		
	Observed ratio of intensities $\frac{I_S}{I_P}$ Scattered / Primary (In arbi		
$\frac{\mu}{\rho}$ Primary	Unintercepted	Alum. x = .135 cm.	Paper = 95 Thick sheets
2.06	1.065 xx	.895 xx	.95 xx
2.27	1.095	.895	1.00
2.33	1.10	.905	1.00
2.10	1.08	.89	.945
1.87	1.06	.835	.945
1.89	1.05	.82	.91
2.16	1.12	.90	1.01) .995)
1.94?	1.11	.89	.99?
1.77	1.07	.83	.90
2.31	1.10	.90	.99
2.17	1.075	.90	.925
1.65	1.05	.81	.88
1.43	1.05	.80	..

Determination of stray effect: Scattering from air etc.

$\frac{\mu}{\rho}$ Primary	Secondary Electroscope Readings	Primary Electroscope Readings	Remarks
2.1	.40	10.0	In taking the ratio $\frac{I_s}{I_P}$ primary electroscope readings were 10 scale-divisions. So the error due to this stray scattering, ranges from .03 to .04, when $\frac{I_s}{I_P}$ is unity
1.64	.30	10.0	
1.72	.30	10.0	
1.56	.30	10.0	
1.40	.30	10.0	
2.06	.30	10.0	
2.50	.30	10.0	

Vide fig. 15 (a) & fig. 15 (b)

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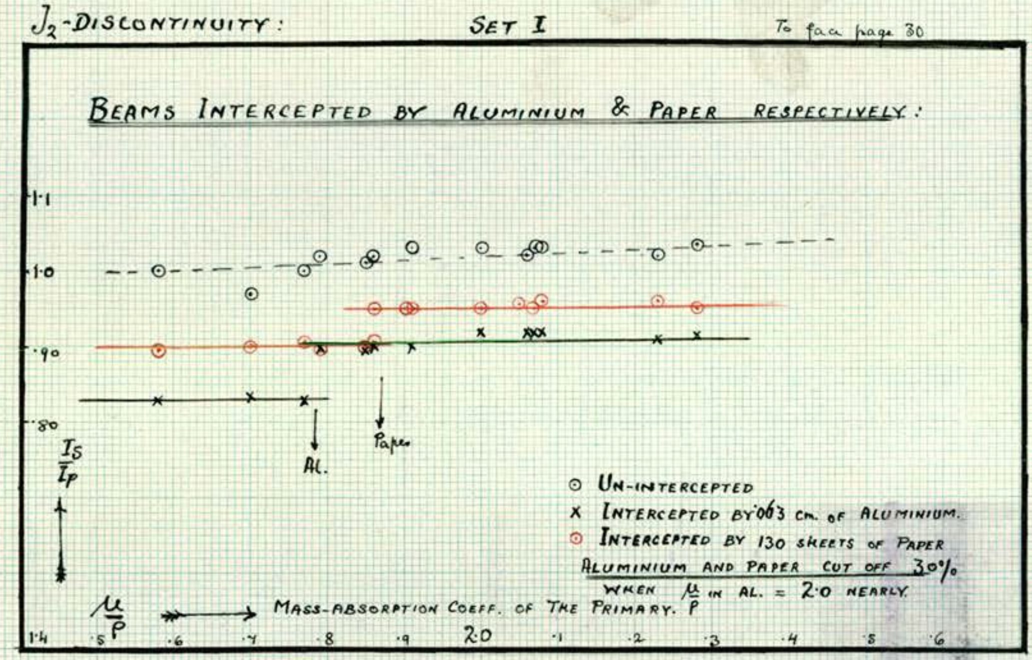

FIG 15 (a)

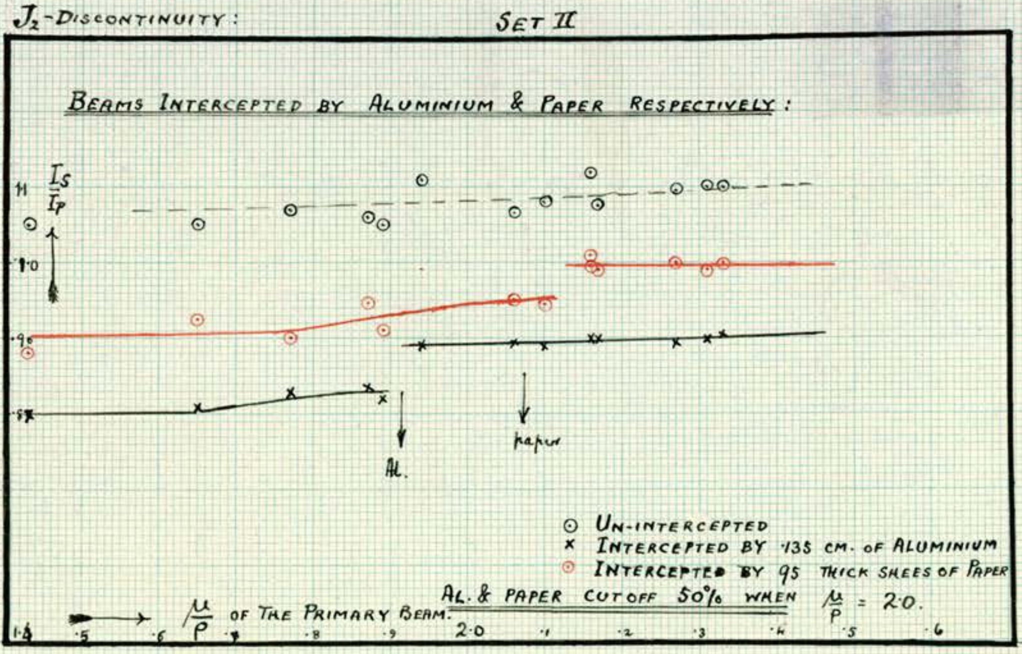

FIG. 15 (b)

should be compared). Then, as the beam is gradually hardened, there is a sudden rise in the absorbability of the secondary beam at the point where the J_1 - discontinuity has been observed in Experiments II. Indication of the J_2 - discontinuity is also evident. Tables XII. (a) & (b) give the experimental results.

It should, here, be remarked that these measurements could not be made, with anything like the accuracy of those previously described; as they involved many more observations. This being so, little time was spent upon them, in comparison with that, expended in the more accurate experiments.

The J-absorption in different substances:

Experiments No. II were repeated with beams intercepted by different absorbing substances; and the positions of the J-discontinuities in other substances were determined. Copper and paper were used as absorbing substances and measurements of $\frac{I_S}{I_P}$, were made for a primary beam of varying wave-lengths. The thickness of the absorbers were adjusted; so that nearly equal fractions of the radiation, were cut off by them, in the region of one particular discontinuity. The regions of J_1, and J_2 discontinuities were studied alone. Table XIII & XIV give the comparative values of $\frac{I_S}{I_P}$ after transmission through different absorbing materials. Figs. 14 (a), 14 (b) & Figs. 15 (a) and 15 (b) represent the same graphically.

Approximate values of the critical absorption ocefficients (measured in aluminium, in the usual way) for different absorbing

Substances are given below:

J_1-discontinuity:

	Paper	Aluminium	Copper
$\frac{\mu}{\rho}$ =	Above 4	3.8	3.5

J_2-discontinuity:

$\frac{\mu}{\rho}$ =	2.1	1.9	2.3

There appears one exception to the rule expressed "the heavier the absorbing element, the higher the critical frequency" - for the J_2-discontinuity in Copper, which appeared for a slightly softer beam than that in aluminium.

Themagnitude of the J-absorption effect, i.e. the magnitude of the absorption steps, in different substances are also different. Judging from observations on the J_2-discontinuity, the effect is much smaller in paper than in copper or aluminium. Copper and aluminium were made to absorb the same amount of radiation only very approximately; so it was not possible to make an exact comparison of the relative magnitude of the steps in these substances.

The J-absorption and C.T.R. Wilson's "fish-tracks"

The J-discontinuities have so far been interpreted as absorption effects in the absorbing substances. The possibility of complications in the ionisation chambers used to measure the radiations should however, be considered. The possibility of these, was demonstrated in C.T.R. Wilson's recent cloud experiments[1], though we had previously[2] given consideration to the possible effects of the superposition of radiations. Wilson's photographic plates revealed a new class of tracks of ions called by him "fish tracks".

1. C.T.R. Wilson, Proc. Roy. Soc. Lon. Vol. CIV Sec. A. 1923.
2. Engineering 1923. BARKLA'S LECTURE IN THE B.A. MEETING. LIVERPOOL.

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J_1 - DISCONTINUITY:

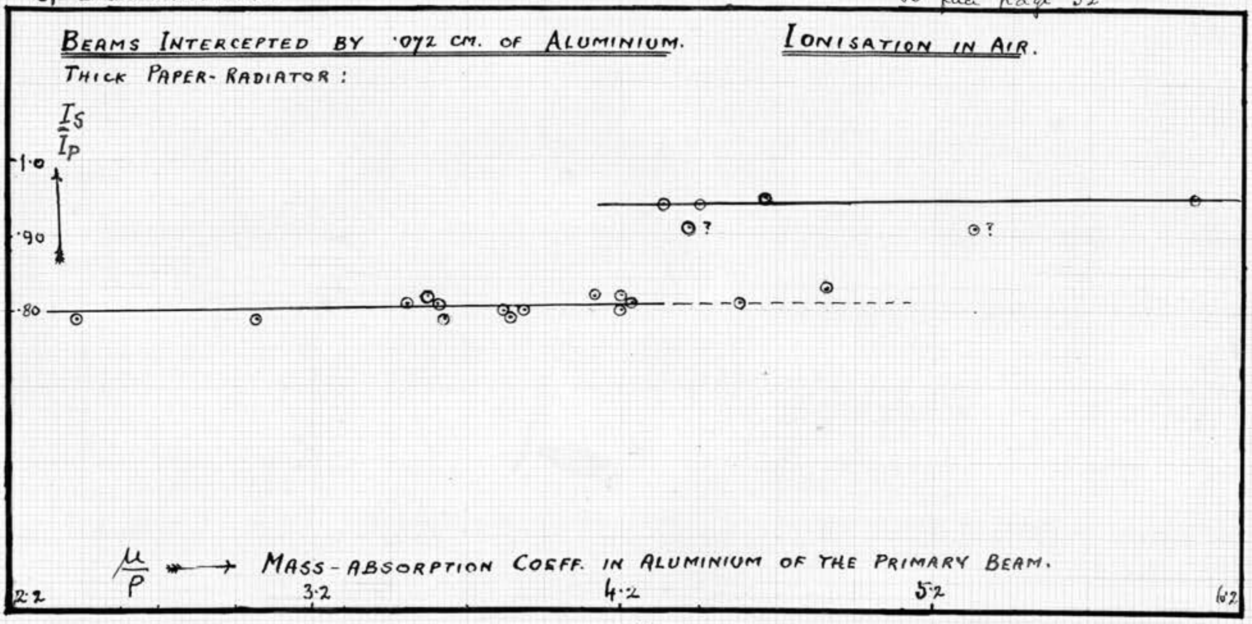

FIG 16(a)

J_2 - DISCONTINUITY:

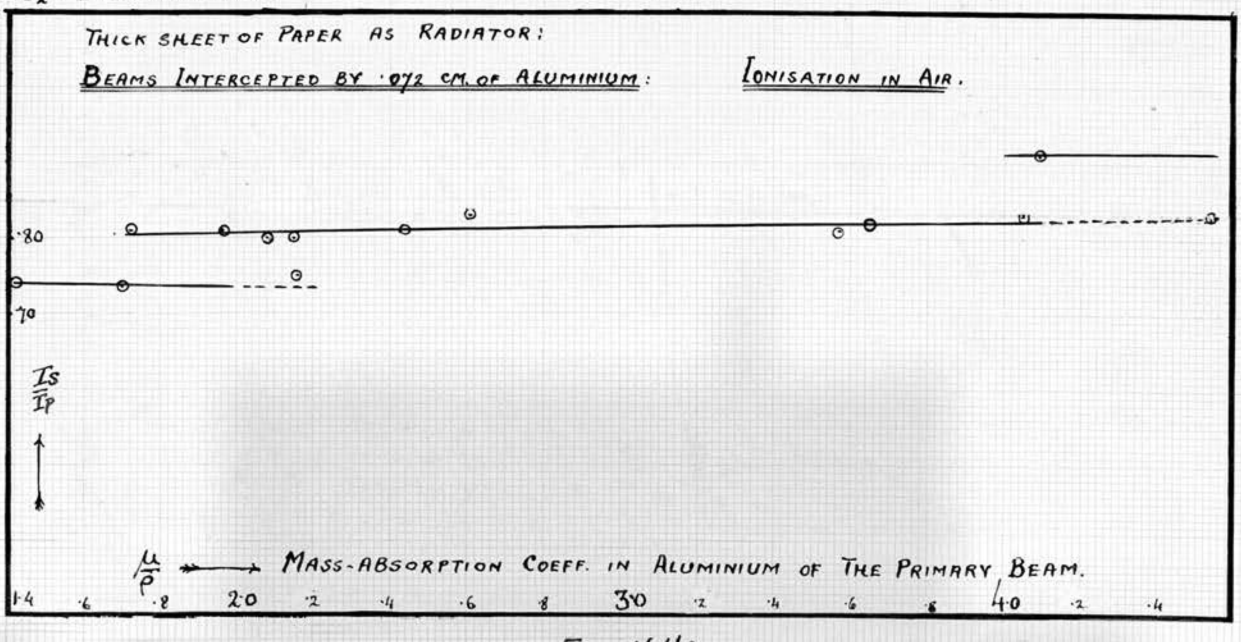

FIG. 16(b)

TABLE XV.

Beams intercepted by .072 cm. of Aluminium: Ionisation in air:

J_1 - Discontinuity		J_2 - Discontinuity	
$\frac{\mu}{\rho}$ Primary	Observed ratio $\frac{I_S}{I_P}$ (in arbitrary units)	$\frac{\mu}{\rho}$ primary	Observed ratio $\frac{I_S}{I_P}$ in arbitrary units.
4.45	.94 xx		
3.85	.81		
4.66	.95	3.57	.81 xy
3.82	.80	1.96	.81
3.60	.79	4.05	.83
4.20	.82	3.65	.82
5.33	.91	2.44	.81
3.84	.79	2.61	.83
3.88	.80	2.16	.75
4.20	.80	2.08	.80
3.02	.83	2.15	.80
2.44	.79	1.70	.735
4.86	.829	1.72	.81
4.12	.82	1.65?	.795
3.50	.81	1.42	.74
6.04	.95	4.54	.83
4.37	.94	4.075	~~.81~~ .91
4.23	.81		
4.58	.81		
4.42	.91		
3.57	.82		

VIDE FIGS. 16(a) + 16(b)

These "fish tracks" were not seen in the plates when the wave-length of the incident radiation, used exceeded .5 Å. The maximum wave-length of the radiation, consistent with the production of these "fish-tracks", Wilson estimates, is between 0.4 and 0.6 Å. Now, it seemed possible that the J-absorption discontinuities might be due to a change in some definite portion of the total ionisation in the gas, and might in fact be connected with the production or non-production of these "fish-tracks" which seem to require special conditions. If these tracks are effects of superposition of radiation in heterogenous beams, the absorber placed in the path of the beam, might get rid of some effective constituents, by filtering and might thus cause a diminution of ionisation in the gas. This would then appear as a big absorption.

The inadmissibility of this interpretation is evident from the following facts: The positions of these discontinuities are different for different absorbers, although they cut off the same amount of radiations. (This is however, not absolutely conclusive, since different absorbers cut off the different constitutents of the beam in slightly different proportions). The magnitudes also of these absorption steps, are different, for different absorbing substances. Furthermore, the positions of these discontinuities, were found within the limits of experimental error, independent of the gas in the ionisation chambers. Table XV and Figs. 16 (a) and 16 (b) give results obtained when intensities of radiations were measured by the ionisation they produced in air - and not in SO_2 as in the previous experiments.

It should be stated here, that C.T.R. Wilson's "fish-tracks" have a possible connection with the J-phenomenon. It is quite possible that the increase in absorption in a substance - the J-absorption - is associated with the production of "fish tracks" in that particular absorbing substance.

Some Features of the J-Phenomenon

It should be pointed out that there was no discontinuity observed (Experiments I) in the ratio $\frac{I_s}{I_p}$ for various wave-lengths, for what had been described as "unintercepted" beams, — although the beams passed through a certain layer of atmospheric air*. Again, as increase in absopption is, in general, associated with increase in ionisation, it might have been expected that a rise in ionisation in SO_2 in the ionisation chamber itself, would occur at certain critical values of mass-absorption coefficients of the beam. The absence of any such ~~kimmx~~ rise leads one to think that either, the increased absorption is not accompanied by an increased ionisation or the density of the absorbing substance (or the compactness of the atoms in the solid condition) ~~xxx~~ influences the J-absorption in some way.

In only two cases - cases when very thin sheets of paper were used as the scattering substance - was there noticed a sudden appreciable rise (as the tube was being hardened up gradually) in the ratio $\frac{I_s}{I_p}$ for "unintercepted" beams. This occurred nearly at the point ($\frac{\mu}{\rho} = 3{\cdot}8$) where the ratio for "intercepted" beams dropped down. If these observations were confirmed, they would indicate a sudden increase in ionisation in SO_2. (The absorption in aluminium is nearly the same as that in S (Sulphur), and so the critical absorption coefficients for increase in ionisation in both lie very close

* The slight ~~drop~~ of 3 to 4% that was observed in these experiments (fig. 2) when $\frac{\mu}{\rho} = 1{\cdot}7$ is most certainly due to absorption in the thin sheet of aluminium used in front of the ionisation chambers.

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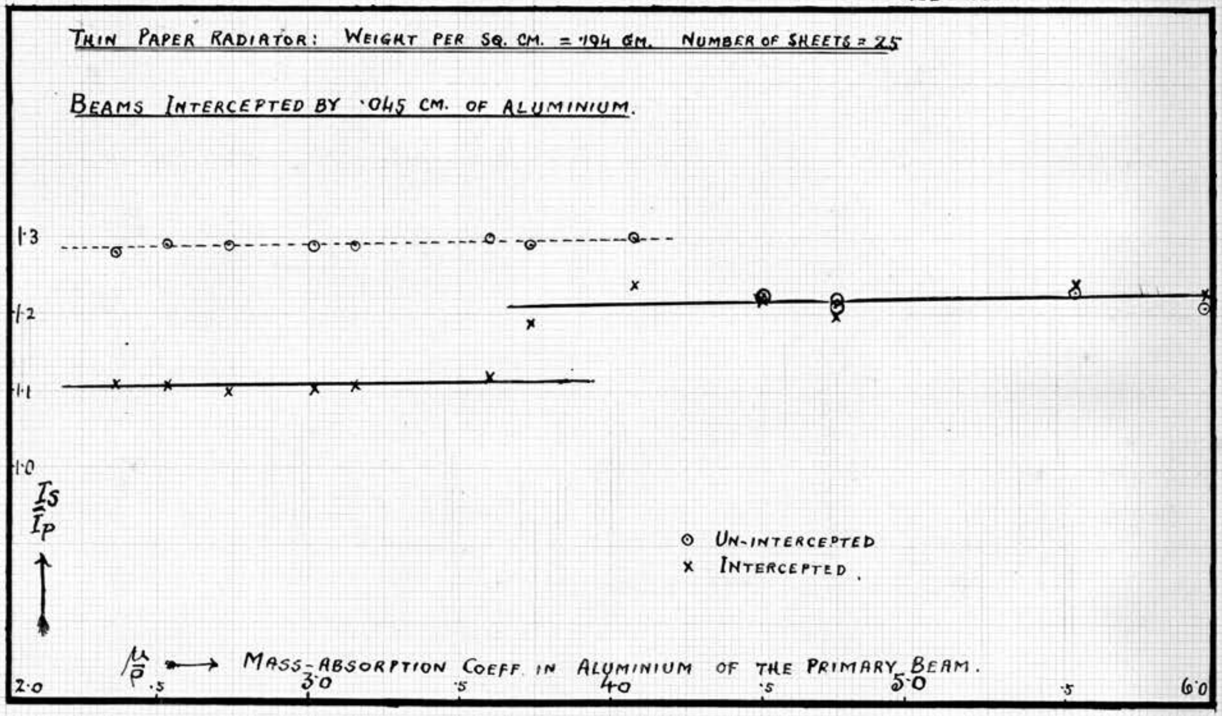

Fig. 17.

TABLE XVI

Observed ratio of intensities $\frac{I_s}{I_p}$ (in arbitrary units)

μ/ρ Primary	Unintercepted	Intercepted by .045 cm. of Aluminium
3.51	1.30 xx	1.12 xx
2.77	1.29	1.20 1·10
2.53	1.29	1.11
2,36	1.28	1.11
3.02	1.29	1.105
3.15	1.29	1.11
3.74	1.29	1.19
4.79	1.21	1.20
4.50	1.22	1.22
4.75	1. 22	1.20
5.97	1.21	1.23
5.54	1.23	1.24
4.08	1.30	1.24

VIDE FIG. 17.

together). The results are given in Table XVl. Fig. 17 represents the same graphically. Any error due to scattering from air or to some extraneous effect was very carefully looked for. This stray effect was very nearly constant over a wide range of wave-lengths.

The Critical Conditions.

Undoubtedly, there are certain critical conditions associated with the J-absorption phenomenon. It has been seen that under apparently the same conditions, the "J" discontinuities vanish altogether in some of the experiments, to appear once again in others. It should be pointed out that these unknown conditions are consistent with the absence of any discontinuity in the absorption experiments of Hewlett[1], and F.K.Richtmyer.[2] Our knowledge about these unknown factors is far too meagre to permit us to make any definite assertion. It seems possible that the phenomenon of J-absorption, is associated with one or more of the following:

1. The polarised condition of the radiations. - This is suggested by the fact that the discontinuity appears more frequently with the scattered beam than with the primary beam. The filtering experiments previously described (Experiments 111) show that the J-discontinuity appears with the scattered beam. The primary beam therefore, in the experiments (Experiments No.11) with "intercepted" beams, behaves in a normal way.
2. The intensity of the radiations.
3. The density of the absorbing material. - The discontinuity has not been observed in air (Experiments I) - although a layer of

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1. Hewlett, Phys. Rev. March 1921, Vol.17, No.3.
2. F.K.Richtmyer, Phys. Rev. July, 1921.

atmospheric air was always traversed by the scattered beam. This leads one to suggest that the closeness of atoms in the solid absorbing material, might have some connection with the J-absorption phenomenon.

4. The previous history of the absorbing material. It seemed quite possible that the state of the absorber has some relation with these critical conditions. Experiments were made with increasing as well as with diminishing wave-lengths, and no difference in the position of the discontinuity was found, i.e. the series of experiments was repeated in reverse order without the least evidence of "hysterisis" or fatigue.

5. The thickness of the radiating substance. Experiments with very thin sheets of paper, as radiator, showed that almost invariably at the soft end, the secondary and primary radiations were of the same penetrating power, as shown by the fact that the ratio $\frac{I_s}{I_p}$ was the same for "unintercepted" as for "intercepted" beams; whereas when a thick radiator was used, there was a decided difference observed in the absorption of the primary and secondary radiations as shown by the difference between the values of $\frac{I_s}{I_p}$ for "unintercepted" and "intercepted" beams. It must be emphasised however, that the two cases are quite distinct; there is no gradation from one to the other; i.e. either, there is exact equality, or there is a clearly marked difference in the absorption of the primary and secondary beams.

Compton's Quantum Theory of Scattering.

The perfect equality in the penetrating powers of the primary and secondary radiations, obtained in the direct measurements of absorption-coefficients, as well as in the experiments with "intercepted" beams (Experiments II) - brings us directly against the very interesting theory of scattering, propounded recently by A.H. Compton. In brief, Compton's theory can be stated as follows: any particular quantum of X-rays is not scattered by all the electrons in the radiator but spends all of its energy upon some particular electron. This electron in return, scatters the ray in some definite direction at an angle with the incident beam. This bending of the path of the quantum of radiation, results in a change in its momentum. As a consequence, the scattering electron recoils with a momentum equal to the change in the momentum of the X-rays. Thus the energy in the scattered ray is equal to that of the incident ray, minus the kinetic energy of the recoil of the scattering electron; and since the scattered ray must be a complete quantum, the frequency will be reduced in the same ratio as the energy. It is expected therefore, on this theory of scattering by quanta, that the wavelength of the scattered X-rays will be greater than that of the incident rays according to

$$\lambda_\theta - \lambda_0 = \frac{2h}{mc} \sin^2 \frac{\theta}{2} = \cdot 0484 \sin^2 \frac{\theta}{2}$$

and when $\theta = 90^\circ$ $\qquad \lambda_\theta - \lambda_0 = \cdot 024 \text{ Å}.$

According to Compton's theory, therefore, there should be a change in wavelength on scattering, even at the soft end. When λ = .7 Å., the change in wavelength which is .024 Å (when the angle of scattering is 90°) amounts to 3%. This would ~~have~~ been accompanied by a 9% change in absorption; whereas in most of the experiments described in the present investigation, the difference in the absorbabilities of the primary and secondary beams cannot be more than about 1%. The effect is certainly not more than a ninth of what would be expected from Compton's theory.

Referring to the exact equality of the penetrating powers of the primary and secondary beams in Barkla & Sale's experiments, A.H. Compton states that the equality might be accounted for, in part, by the effect of heterogeneity of the X-ray beam; for, the soft constituents of the scattered beam are mostly absorbed by ~~the thickness of the~~ radiator, and the penetrating parts of the incident primary beam, are scattered in greater proportion. This suggestion is not at all tenable; because very thin radiators were used in Barkla & Sale's ~~these~~ experiments, absorbing only a very small fraction of the radiation - and in addition to this, the primary and secondary beams passed through equal thickness of the radiator. So the difference in two small effects, must be almost infinitesimal.

It should be mentioned here, that the absorption measurements of S.J. Plimpton[1] showed that Molybdenum and Rhodium radiations suffered no change of wavelength on scattering. Repetition of Plimpton's experiments by Compton[2] however, showed an increase in the absorption-coefficient of the secondary radiation. Referring to the radiation reflected from a crystal, the experimental results of Overn,[3] Duane & Patterson[4] and Kulenkampff,[5] very clearly show that there is no change in wavelength of the reflected rays*.

Thus, so far as absorption measurements are concerned, there is no reason to question the validity of J.J. Thomson's classical theory of scattering. The increased absorption of the secondary beam is due to the J-absorption, taking place in the body of the absorber, or of the radiator, or in both and since the J-absorption

1. S.J. Plimpton, Phil. Mag. 42, Sept. 1921 3. Overn, Phys. Review 14, 1919
2. A.H. Compton, Nature, Nov. 17, 1921 4. Duane & Patterson, Phys. Rev. 16, 1919.
5. H. Kulenkampff, Zeits. f. Phys. 19, 31st Oct. 1923.

* Compton explains the negative result in the case of reflection from a crystal, being due to the simultaneous scattering of the same quantum by a large number of electrons.

has been seen to depend on some critical conditions, it is quite reasonable to conclude that, at one time (at the soft end) one might get equality in the absorption coefficients of the primary and the secondary beams, while at other times, one might expect an increase in absorption of the secondary beam. So, Plimpton's experiment showing the null-effect is as genuine a result as the repetition of it, by Compton, showing a positive effect.

Evidences from Spectroscopic measurements by Compton & Ross on the other hand, seems to support Compton's theory of scattering. In the spectrum of the secondary X-rays, A.H. Compton and P.A. Ross[1] observed two distinct lines - one corresponding exactly to the wavelength of the primary radiation and the other corresponding to a slightly longer wavelength; - the increased wavelength remarkably agreeing with Compton's theoritical value. Compton's spectroscopic measurements of the wavelength-shifts, for different angles of scattering, fitted quite satisfactorily with what his theory demands. Quite contradictory results however, were also obtained very recently by Clark & Duane[2] in a series of experiments. In the spectrum of radiation scattered by radiators of low atomic number (e.g. lithium) there was observed only one "peak", corresponding exactly with the wavelength of the primary radiation; whereas, when radiators of high atomic number were used, there were observed two "peaks" - one corresponding to the wavelength of the primary radiation, and the other, at positions varying with the atomic number of the radiating substance. The latter "modified" peak, was interpreted by Clark & Duane as being due to the tertiary radiations, emitted as a result of the bombardment of the atoms of the scattering substance by

2. Clark & Duane, Proc.Nat.Acad. of Sc. Dec. 1923, Jan & Mar. 1924
1. P.A. Ross, Proc. Nat. Acad. Science, July 1923.

electrons ejected by the primary radiations. *

Judging from both these positive and negative results in the spectroscopic work and considering all the absorption experiments in the present investigation, one is led to think that the wave-length shift observed in the spectrum of X-rays, is ~~certainly~~ probably connected with the J-absorption phenomenon in some way. The sudden increase observed in our absorption experiments, in the absorbability of the secondary beam - it is interesting to notice - agrees closely in magnitude with the change in absorption, corresponding to the change in wavelength on scattering, according to Compton's theory. It is premature, at the present stage of our knowledge, to attempt an explanation of the apparent wavelength-shift, in terms of the J-absorption phenomenon; but it can be pointed out that one need not assume any change in wavelength in the process of scattering, in order to interpret the spectral shift; for it has been seen that, there is a slight increase in the absorbability of the beam, after the large absorption, in a thin layer of the absorbing substance, and as has already been pointed out, there is a possibility that this rise in the absorbability, is a rise, not only in that particular absorbing substance, but also in other substances, i.e. there is a slight increase in the wavelength of the transmitted beam,

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* One feels extremely doubtful, whether the intense peaks observed by Compton, could be accounted for, by these tertiary radiations. The efficiency of production of these radiations is far too small, to give such an intense peak, and on the other hand, the spectra are very narrow, as contrasted with wide continuous spectra of X-rays. See Webster, Abstracts of the Proc. of American Phys. Soc. Phys. Rev. May, 1924.

.fter the enormous absorption which has been shown to take place in . thin layer of the absorber. If experiments justify this view of a change n wave-length during transmission, the wavelength-shift in all spec-;roscopic measurements, might find an explanation. This however, is not .n the process of scattering. The "J" absorption might take place in the)ody of the radiator (which in all the experiments of Compton and Ross ιre apparently not thin) or it might take place in the crystal, the evidence of which has been shown by Owen[1], in Carborundum crystal. The wavelength-shift, might then be due to the increase in wavelength of the transmitted beam, after the large absorption associated with the J-absorp-;ion phenomenon. Experiments are in progress to decide this point.

Another possibility of explaining the Compton-shift along quite a different line can be suggested here. It is conceivable, that at particular absorbabilities of the radiation, when the J-absorption takes place in the crystal, the refraction index suffers a considerable change; thus causing a shift of the spectral line. This however, at present, is a little more than speculation.

Summary.

The conclusions from all the experimental results embodied in the previous pages, are briefly summarised below:

1. The difference in the absorption between the primary and secondary beams of X-rays which is observed, generally at the hard end, has hitherto lent support to the idea of a transformation taking place in the radiator. There have been two alternative ideas of transformation namely, (1) the excitation of a characteristic radiation by the scattering substance and (2) a real change in wave-length —

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1. Owen, Proc.Roy.Soc.Lon.1919.

in the process of scattering. The experiments in the present investigation support neither view. There is no appreciable excitation of a fluorescent radiation in the radiator. There is no evidence of a change of wavelength in thefundamental process of scattering, though many results have been obtained which have led others to a different conclusion.

II. Whereas, most experimenters have found either very close similiarity between the primary and secondary radiations, or a well-marked difference between them, these investigations have shown the transition from one to the other, i.e. from the "unmodified" scattering to the "modified" scattering.

III. An "unmodified" scattered radiation may, by simple filtering be suddenly transformed into a "modified" radiation, showing conclusively that in this case at least, the transformation is not in the scattering substance. The apparent changes in the radiation, in the process of scattering, depend both in position and magnitude, upon the material and the thickness of the absorbing substance used to test the primary and secondary radiations.

IV. In all cases when a transition from an "unmodified" to a "modified" radiation, has been observed, it can be explained in terms of the J-absorption phenomenon.

V. The J-absorption discontinuities which were first observed by Barkla & White, have been further investigated. Two other discontinuities, having the same characteristics, have been observed in the present investigation. One of these agrees with the discontinuity observed by Barkla in his ionisation experiments with characteristic radiation, and also with that obtained by Williams in his absorption experiments with homogeneous radiations.

The main features of the J-absorption phenomenon have been studied, and the following generalisations are made:

(1) There are certain critical values of the absorption coefficients of X-radiations at which a very abrupt rise in absorption in different absorbing substances, is frequently observed.

(2). The values of the critical absorption coefficients (as measured in one substance) depends upon the absorbing substance; the magnitude of the anomalous absorption also depends upon the absorbing substance.

(3). The critical point at which the J-absorption phenomenon is shown, does not appear to be so closely associated with a wavelength (say of a constituent of the radiation experimented upon), as with the absorbability of the radiation as a whole, i.e. with energy absorption.

(4) The J-absorption phenomenon is characterised by two features:

(a) a large absorption in a thin layer of the absorbing substance, and

(b) a subsequent slightly increased absorbability of the transmitted beam.

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(5). The discontinuities disappear altogether in some experiments to appear once again in others under what are apparently the same conditions. Undoubtedly there are some critical factors conditioning the phenomenon. The critical factors have not yet been identified.

(The enormous variety of conditions, under which the phenomenon has been observed in this laboratory, entirely preclude the possibility of an explanation, in terms of experimental errors, or of possible processes, not fundamental in character).

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